82d Congress, 2d Session } SENATE { Document No. 103

MANPOWER, CHEMISTRY, AND AGRICULTURE

STAFF REPORT

TO THE

SUBCOMMITTEE ON LABOR AND LABOR-MANAGEMENT RELATIONS

OF THE

COMMITTEE ON LABOR AND PUBLIC WELFARE
UNITED STATES SENATE

EIGHTY-SECOND CONGRESS
FIRST SESSION

ON

MANPOWER, CHEMISTRY, AND AGRICULTURE

PRESENTED BY MR. HUMPHREY

February 20 (legislative day, January 10), 1952.—Ordered to be printed, with illustrations

UNITED STATES
GOVERNMENT PRINTING OFFICE
95402 WASHINGTON : 1952

COMMITTEE ON LABOR AND PUBLIC WELFARE

JAMES E. MURRAY, Montana, *Chairman*

LISTER HILL, Alabama	ROBERT A. TAFT, Ohio
MATTHEW M. NEELY, West Virginia	GEORGE D. AIKEN, Vermont
PAUL H. DOUGLAS, Illinois	H. ALEXANDER SMITH, New Jersey
HUBERT H. HUMPHREY, Minnesota	WAYNE MORSE, Oregon
HERBERT H. LEHMAN, New York	IRVING M. IVES, New York
JOHN O. PASTORE, Rhode Island	RICHARD M. NIXON, California

WILLIAM H. COBURN, *Clerk*

SUBCOMMITTEE ON LABOR AND LABOR-MANAGEMENT RELATIONS

HUBERT H. HUMPHREY, Minnesota, *Chairman*

MATTHEW M. NEELY, West Virginia	ROBERT A. TAFT, Ohio
PAUL H. DOUGLAS, Illinois	WAYNE MORSE, Oregon
JOHN O. PASTORE, Rhode Island	IRVING M. IVES, New York

JACK BARBASH, *Staff Director*
MARJORIE WHITTAKER, *Clerk*

INTRODUCTION

The Subcommittee on Labor and Labor-Management Relations has been engaged in extensive staff work on various phases of the manpower problem. As part of this general project, Dr. Francis Joseph Weiss, a special staff consultant to the subcommittee, has prepared a study of the manpower implications of chemical agriculture.

Dr. Weiss' line of investigation is simple enough. The increasing use of chemicals on the American farm is resulting in substantial reductions in labor requirements. If this use continues at the prevailing rate, it will inevitably result in sizable movement of people away from the family farms and the rural areas of the United States. The family farmer in our Nation represents a basic bulwark of the American way of life; and we have a responsibility, therefore, to minimize the disruptive consequences of the innovations, which Dr. Weiss documents, on the social fabric of our agricultural life.

The author of this staff study is singularly well qualified. He has a doctor of philosophy degree in the natural sciences and a doctor of science degree in social science. He has had extensive professional experience with the Sugar Research Foundation, United States Department of Agriculture, thus giving him the technical competence and the social vision to deal intelligently with this extraordinarily complex problem.

As is the prevailing rule with staff studies, the emphasis is on the factual material. Such conclusions and recommendations as are made do not purport to commit any member of the subcommittee.

Hubert H. Humphrey.

CONTENTS

MANPOWER, CHEMISTRY, AND AGRICULTURE [1]

I. Introduction: The Rise of Chemical Industry

We are living in what has often been called the chemical age, which means that man has finally succeeded in his century-old endeavors to rearrange the molecular structure of natural matter, so as to provide himself with an infinite series of synthetic or biological products serving almost every conceivable purpose. The chemical discoveries of recent years may ultimately prove to be even more revolutionary in their impact than those that led to the mechanical revolution which resulted from a more efficient utilization of energy.

Chemistry pervades almost all branches of manufacture, and modern industry is inconceivable without its chemical foundation and the manifold products supplied by the chemical industry. The printer depends on it for his ink, the weaver for his dyes, the tanner for his tans, the blacksmith and tinner for welding material, the miner and railroad builder for dynamite, the glassmaker for fluxing material. Innumerable are the chemicals needed by the druggist, the physician, and the veterinarian, and a great many chemical substances are now being used to make food more nutritive, more palatable, and longer lasting.

Trade and industry availed themselves at an early stage of the fruits of chemical discovery and chemical industry. But agriculture, by nature more conservative, was in the beginning rather tardy in adopting new methods and devices based upon chemical research and the availability of new substances that are able to improve the growth, reproduction, or quality of plant and animal products as well as the efficiency of agricultural production.

However, once synthetic fertilizers had been adopted to supplement insufficient amounts of plant food available in the soil, it was only natural to insure full return from this new and costly expenditure by applying other chemicals to protect the crop against disease and pests and against the encroachment by noxious weeds. Thus, step by step, the introduction of one chemical opened the way for the application of another one, until chemicals have become as important to modern agriculture as the plow and the hoe (1). In many instances they are assuming the place of manual or mechanical farm operations or greatly increasing their efficiency; and by this way they accelerate a trend which has been observable all through the last century toward restriction of human labor in the production of food and natural fibers.

In spite of their enormous importance for modern life the products of chemical industry are rarely recognized by the ultimate consumer since they do not reach him as such, but consitute only raw or auxiliary products. Thus he might not be fully aware to what extent they shape his life. A structure in the course of erection gives evidence of the importance of steel industry, the roads and highways present the marvels of automotive engineering, the tall cornfields

[1] Prepared by Francis Joseph Weiss, special consultant to the Subcommittee on Labor and Labor-Management Relations.

impress upon all observers the great success of plant breeding, but, except for the scientist and engineer, there is no sign of the chemical control which lies back of the production of satisfactory steel or of the fertilizers, insecticides, and fungicides that assure the prolific growth of plants (2).

This is also the reason why the general public does not realize the role chemistry and chemical technology plays in the displacement of labor in industry and agriculture. The power loom is very conspicuous and so is the reaper, the tractor, the cotton picker. Here displacement of manual labor is apparent and has caused violent reaction on the part of the displaced workers, but also led to social legislation to make the transition from hand to machine work less calamitous to the affected people. However, the action of detergents, adhesives, weed killers, plant hormones, trace elements, or antibiotics as feed supplements are much less visible and, in many instances, minute amounts of chemicals may exert astonishing effects. For this reason the economic and social impact of chemical discoveries, inventions, and applications has never given as much attention in social and labor legislation as was accorded to the various mechanical inventions that heralded the age of the industrial revolution.

Now we are standing in the midst of a chemical revolution that arises from our deeper understanding and more efficient use of matter (3). The application of chemical methods and substances in various fields of industry and agriculture has spread much faster than the introduction of new machinery and, while the application is still in its incipient stage, has led to extraordinary economies in time, material, and labor, especially in agriculture and horticulture. Witness the enormous expansion in the production of the so-called industrial chemicals, under which name all those basic products are subsumed that enter subsequent processing. They thus comprise also agricultural chemicals, which during the last decade showed faster production and consumption increase than any other group of chemical products.

Until the end of the last century the United States was behind Great Britain and Germany in the development of its chemical industry. But the development of the continuous process in the United States which replaced the old batch method brought about such an expansion of chemical production that even during the depression of the 1930's our production exceeded the combined output of Germany, Great Britain, France, Italy, Japan, and Russia.

The second World War forced the American chemical industry to use its already large capacity to the fullest to satisfy the wartime needs of this Nation and consequently led to further great expansion of chemical production. The rate of increase has been much greater than that of all industrial production, as can be seen by comparing the respective index numbers issued by the Board of Governors of the Federal Reserve System (4). These index figures constitute over-all measures of changes in the physical volume of production and do not reflect price changes; the base period is the average of the years 1935 till 1939. As we can see from table I and chart I, the total industrial production was subject to extreme fluctuations caused by depression, technical progress, and war, while chemical production exhibits a steadier expansion. However, in sharp contrast to both stands the almost eruptive expansion of industrial chemicals which is in no small measure due to the rapid increase of demand in such agricultural chemicals as insecticides, fungicides, and herbicides, most of which were unknown but a few years ago. It is unfortunate that the series of annual indexes for industrial chemicals starts with the relatively recent year 1939. However, the steep rise from 120 in that year, as compared with the base period 1935–39, to 455 in 1950 permits an assumption for the period immediately preceding the year 1939. We may therefore validly conclude that this branch of chemical production developed from a very modest beginning in less than 20 years to an important factor in our national economy.

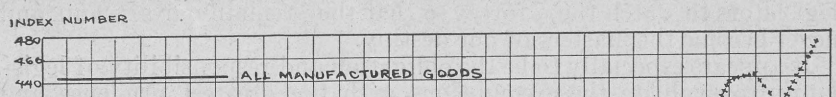
TABLE I.—*Annual index of industrial production*[1]

[Average 1935–1936=100]

Year	All manufactured products	Chemical products	Industrial and agricultural chemicals	Year	All manufactured products	Chemical products	Industrial and agricultural chemicals
1919	72	[2] 52	----------	1935	87	89	----------
1920	74	----------	----------	1936	104	99	----------
1921	56	[2] 41	----------	1937	113	112	----------
1922	74	----------	----------	1938	87	96	----------
1923	86	57	----------	1939	109	112	120
1924	81	56	----------	1940	126	130	153
1925	90	63	----------	1941	168	176	210
1926	95	70	----------	1942	212	278	286
1927	94	73	----------	1943	258	384	367
1928	99	78	----------	1944	252	324	404
1929	110	89	----------	1945	214	284	392
1930	90	87	----------	1946	177	236	394
1931	74	78	----------	1947	194	251	432
1932	57	68	----------	1948	198	254	442
1933	68	76	----------	1949	183	241	414
1934	74	83	----------	1950	209	264	455

[1] Federal Reserve Board (4).
[2] Fabricant (6).

CHART I.—ANNUAL INDEX OF INDUSTRIAL PRODUCTION
(1935–39=100)



95402—52——2

At this moment, when our country has established itself as the leader in world trade, industry, and agriculture, the chemical industry is recognized as one of the prime factors of economic and social development. Its growth has been so rapid and is of such recent date that we have not yet become fully aware of the implications of this event for our national destiny (5). Especially the impact of the rapidly expanding use of chemical products in agriculture and industry upon labor requirement deserves careful study, in order to ascertain probable changes that the new technological and agronomic practices will have on the future labor market.

We are wont to consider chemicals as palpable materials that can replace natural products or give them certain desired qualities. But the idea of chemical products performing work that heretofore has been done by hand or machine is so new that we have to adjust our entire economic thinking to this unaccustomed situation. The concept of working chemicals is the more difficult to grasp for those not familiar with recent developments in chemical technology and agricultural chemistry as most of them, in contrast to machines, perform their task silently and unobtrusively lose their identity or disappear entirely in carrying out the services assigned to them.

While our society has reached some degree of maturity in the application of mechanic, thermodynamic, and electromagnetic forces, the forces that lie hidden in the molecule, and still more the energies that are concentrated in the atom have not yet been tamed to the same degree of perfection for the service of man. Yet what we know already about them, and what we have learned by very recent practical experience, shows the unimaginable potentialities for good or bad that scientific research may put in our hand. However, since these chemical forces, no matter how extensive or efficient they be, are not the ultimate values in human society, but only potential means in the pursuit of happiness, it is the duty of social scientists, statesmen, and legislators to watch these forces so that they remain our servants and never become the masters of our destiny.

It appears especially to be the obligation and responsibility of legislators to evaluate these conditions with the greatest prudence and foresight, in order to achieve with a minimum of interference in the individual life and technological and economic progress, a maximum of employment security, economic stability, and general welfare. Considering the strong tendency of all technological revolutions to concentrate economic power in the hand of a few to the detriment of the majority of the people, it will be especially necessary to channel the new chemical productive forces into such furrows that they fertilize the entire economy of our Nation. It will also be necessary to protect the laboring man as well as the Nation as a whole against potential damage, health hazards, fire hazards, etc., that the presumably rapid introduction and universal application of working chemicals will be attended with.

At the present time the great demands on manpower and material caused by the necessity for military preparedness and industrial mobilization has lessened the impact of chemical labor-saving devices in industry and agriculture. One can well visualize, however, a time when the ready availability of chemical products that are now in short supply, and the return of millions of defense workers to their normal occupation, will bring great hardship and economic dislocations that will hit especially the rural areas which in times of recession provided formerly some measure of employment opportunity. We must not let ourselves be deceived by the present unusual situation.

In fact, the emergence of what I should like to call chemical agriculture is bound to bring about revolutionary changes in this oldest human industry. We are at the threshold of a new era that promises plentiful food and fiber, but is also fraught with the dangers of economic and social disruption against which we have to prepare our Nation no less than against the dangers of armed aggression.

II. Chemical Agriculture

1. THE SECULAR TREND IN AGRICULTURAL PRODUCTION AND EMPLOYMENT

Since time immemorial the pursuit of agriculture has been the fundamental activity of the human race. For this reason the conditions under which this activity takes place are of extreme importance, not only for the occupational distribution and the employment situation of every nation but to the welfare, economic prosperity, and political stability of the world. Even in our time, when the effects of industrialization are felt in the remotest corners of this planet, four-fifths of the demand for manufactured products come from the tillers of the soil; and, though we have made tremendous progress in agricultural mechanization, the overwhelming majority of the world's population is still engaged in the manual process of food production and—as we may add—has not yet been able to produce enough to satisfy the essential needs of the human body.

Against this background of world agriculture we have to consider the spectacular developments that took place in American agriculture during the relatively short period of a hundred years. For only in its historical and geographical setting we will understand the pattern of the present agricultural employment situation and shall be able to better evaluate the actual trend.

The era preceding and also partially overlapping the period of chemical agriculture was that of agricultural mechanization which was an outgrowth of the industrial revolution, the change from muscle-driven to power-driven machinery. Although this revolution started in the latter part of the eighteenth century, it was not until the middle of the nineteenth century that it affected American agriculture; but once adopted, it gained momentum with such speed that it changed within a few decades not only the employment conditions of our Nation but also its occupational and geographical distribution and its very way of life. In 1820, 71.8 percent of the gainfully employed were occupied in agricultural pursuits and 28.2 in nonagricultural work. In the year 1940 only 17.6 percent were occupied in agriculture and 82.4 in nonagricultural pursuits. This radical change is illustrated in the following table:

TABLE II.—*Percentage distribution of the labor force* [1]

Year	Nonagricultural pursuits	Agricultural pursuits	Year	Nonagricultural pursuits	Agricultural pursuits
1820	28.2	71.8	1890	57.4	42.6
1830	29.5	70.5	1900	62.5	37.5
1840	31.4	68.6	1910	69.0	31.0
1850	36.3	63.7	1920	73.0	27.0
1860	41.1	58.9	1930	78.6	21.4
1870	47.0	53.0	1940	82.4	17.6
1880	50.6	49.4			

[1] Census (7).

The shift of the gainfully employed part of the population from agricultural to nonagricultural pursuits coincides with the introduction of modern farm machinery and is also correlated with the increased output per farm worker. This is shown in the following table and graphically illustrated in the subsequent chart:

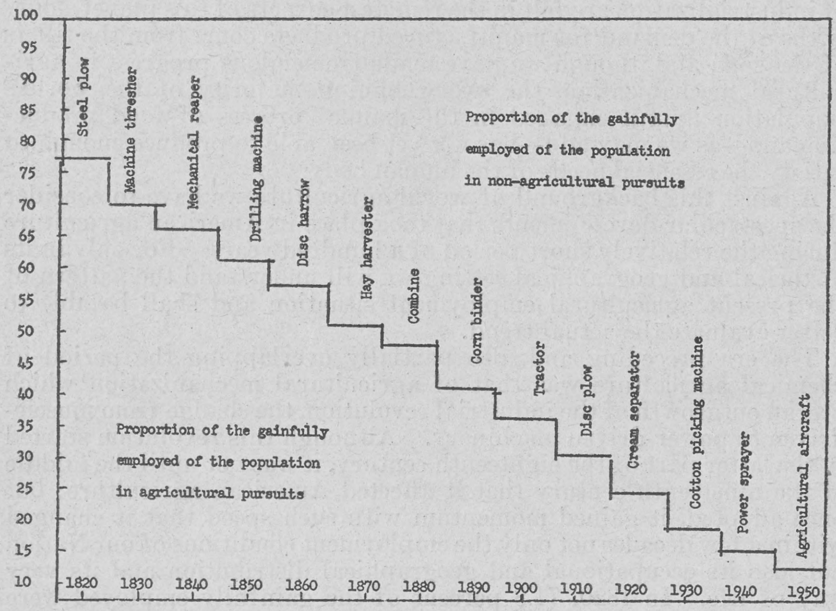
TABLE III.—*Output per farm worker* [1]

[1870=100]

Year	Total output	Employment	Output per farm worker	Year	Total output	Employment	Output per farm worker
1870	100	100	100	1910	273	169	162
1880	150	125	120	1920	299	167	179
1890	189	145	130	1930	345	153	225
1900	238	159	149	1940	378	134	284

[1] Barger (8).

CHART II.—PERCENTAGE OF LABOR FORCE ENGAGED IN AGRICULTURE IN RELATION TO THE DEVELOPMENT OF FARM MACHINERY



Introduction of farm machinery has resulted in geographic shifts toward land of level topography, particularly to cheap land of low rainfall in the Western States which could be economically cultivated with modern farm machinery. This tendency has reacted unfavorably upon many humid areas in the East and Southeast which were topographically less fitted for extensive agriculture and the introduction of farm machinery (9). In these areas of intensive agricultural production a new form of agriculture which avails itself more of chemical than of mechanical methods promises the greatest labor economies and consequently a high degree of technological displacement of farm workers.

There are many women, children, and older farm workers among those gainfully employed in agriculture who naturally accomplish less than an adult male worker could do in the same time. There is much part-time work in agriculture and finally the work hours per week have been greatly reduced during the last century. For all these reasons it is quite inaccurate to measure agricultural employment by the number of people employed in agriculture; the only rational and scientific way of doing it is to count the man-hours used by adult males required for the performance of the farm operations and express total farm labor requirements in terms of man-equivalent hours as has been done by Hecht and Barton (10) and is now generally adopted by the Bureau of Agricultural Economics of the United States Department of Agriculture. Only by means of man-hour equivalents can we obtain a clear picture of the trend in agricultural employment and the basis for extrapolating this trend into the near future.

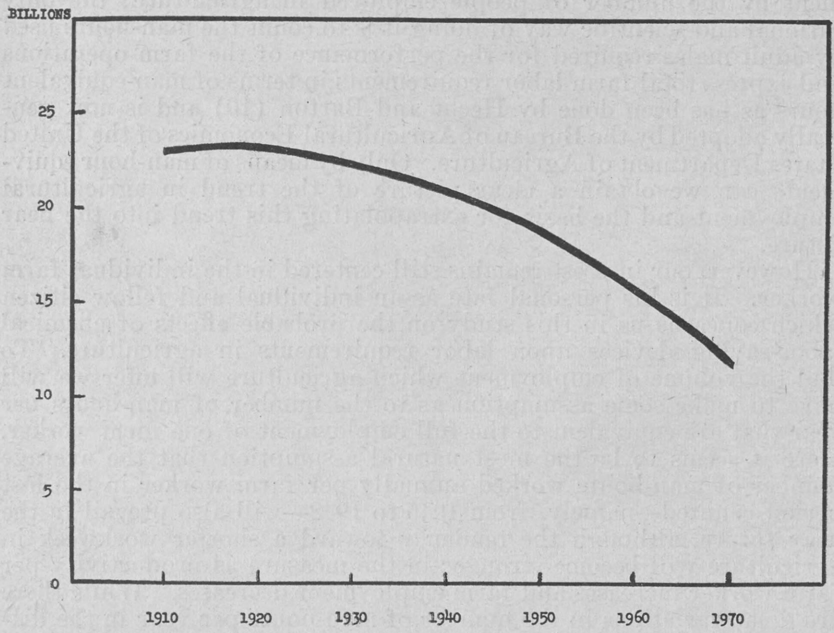
However, our interest remains still centered in the individual farm worker. It is his personal fate as an individual and fellow citizen which concerns us in this study on the probable effects of chemical labor-saving devices upon labor requirements in agriculture. To find the volume of employment which agriculture will offer we will have to make some assumption as to the number of man-hours per year that are equivalent to the full employment of one farm worker. Here it seems to be the most natural assumption that the average number of man-hours worked annually per farm worker in the last period counted—namely, from 1945 to 1948—will also prevail in the near future, although the tendency toward a shorter workweek in agriculture will become stronger in the measure as productivity per farm worker increases and farm employment decreases. While there are great variations in the number of man-hours per year in the different geographic divisions of our country—it was 1,496 in New England and 2,379 in the Pacific States—the average for the total United States has remained constantly since 1920 near 2,000 man-hours per year (11). It is therefore proposed to divide the total man-hour requirements per year by 2,000 in order to obtain the approximate number of gainfully employed people in agricultural pursuits. It is natural that the figures of agricultural workers obtained by this method are and ought to be higher than those given by the Bureau of the Census since many people whose main occupation lies in industry contribute to the total number of man-hours in agriculture through occasional or seasonal work on the farm (12).

In all these calculations no distinction is being made between farm operators and hired farm workers since, technologically, man-hour input of operators and farm workers is mutually exchangeable. Although the trend toward mechanization and rationalization of agricultural production will lead to a decrease of both number of farms and farm workers, the ratio of decrease will vary according to economic circumstances, while labor-saving devices will affect the total number of man-hours required for all farm operation.

Table IV indicates in column (1) the number of man-hours for all farm work in millions per year (13).[1]

In 1910 the gross farm production had an aggregate value of about \$8 billion calculated on the basis of the average dollar value of the years 1935–39, while in 1950 the aggregate deflated dollar value of the gross farm production was about \$12 billion. However, while the

CHART III.—MAN-HOURS OF LABOR REQUIRED FOR FARM WORK, UNITED STATES, 1910–70



1910 production required 22.9 billion man-hours, the much greater production of 1950 could be accomplished with only 18.6 billion man-hours. If this trend prevails for the next 20 years, we will need only 15.6 billion in 1960 and 11.7 billion man-hours in 1970. However, it is doubtful whether the upward trend of agricultural production will continue at the same rate. It is more likely that it will rise at a slower pace, in which case, of course, the man-hour requirements would decrease even faster than under the assumed unaltered conditions of agricultural expansion.

[1] The original figures taken from the Agricultural Statistics, 1950, for 5-year averages from 1910 to 1949 were fitted into a time series by the method of least squares using the method of cumulative additions (14) and extrapolated to 1970. As can be seen from graph III, the secular trend of man-hour requirements for agricultural production shows the form of a parabola which reaches its peak in 1917 and then goes downward with increasing slope. This can be expressed by a regression equation of the second order:

$$Y = 22{,}919 + 53x - 4x^2 \quad . \; . \; . \; (1)$$

in which x expresses the time in years starting with 1910 and Y the man-hours in millions per year.

TABLE IV.—*Percentage of agricultural workers in total labor force*

Year	Agricultural man-hours in millions (1)	Agricultural workers in thousands (col. 1÷2,000) (2)	Total labor force in millions [1] (3)	Percent of total labor force (4)
1910	22.919	11,460	37.2	30.8
1911	22.968	11,484	37.6	30.5
1912	23.009	11,505	38.0	30.3
1913	23.042	11,521	38.4	30.0
1914	23.067	11,534	38.8	29.7
1915	23.084	11,542	39.2	29.4
1916	23.093	11,547	39.6	29.2
1917	23.094	11,547	40.0	28.9
1918	23.877	11,939	40.4	29.6
1919	23.072	11,536	40.8	28.3
1920	23.049	11,525	41.2	28.0
1921	23.018	11,509	41.9	27.5
1922	22.979	11,490	42.6	27.0
1923	22.932	11,466	43.3	26.5
1924	22.877	11,439	44.0	26.0
1925	22.814	11,407	44.7	25.5
1926	22.743	11,372	45.4	25.0
1927	22.664	11,332	46.2	24.5
1928	22.577	11,289	47.0	24.0
1929	22.482	11,241	48.6	23.5
1930	22.379	11,190	49.3	23.0
1931	22.268	11,134	49.3	22.6
1932	22.149	11,075	50.3	22.2
1933	22.022	11,011	50.7	21.7
1934	21.887	10,944	51.4	21.3
1935	21.744	10,872	52.1	20.9
1936	21.593	10,797	52.8	20.4
1937	21.434	10,717	53.6	20.0
1938	21.267	10,634	54.4	19.5
1939	21.092	10,546	55.2	19.1
1940	20.909	10,455	56.0	18.7
1941	20.718	10,359	57.4	18.0
1942	20.519	10,260	60.2	17.0
1943	20.312	10,156	64.4	15.8
1944	20.097	10,049	65.9	15.2
1945	19.874	9,937	65.1	15.3
1946	19.643	9,822	60.8	16.2
1947	19.404	9,702	61.6	15.8
1948	19.157	9,579	62.7	15.3
1949	18.902	9,451	63.6	14.9
1950	18.639	9,320	63.5	14.7
1951	18.368	9,184	64.2	14.3
1952	18.089	9,045	65.0	13.9
1953	17.802	8,901	65.8	13.5
1954	17.507	8,754	66.5	13.2
1955	17.204	8,602	67.3	12.8
1956	16.893	8,447	68.1	12.4
1957	16.574	8,287	68.9	12.0
1958	16.247	8,124	69.8	11.6
1959	15.912	7,956	70.7	11.3
1960	15.569	7,785	71.6	10.9
1961	15.218	7,600	72.6	10.5
1962	14.859	7,430	73.6	10.1
1963	14.492	7,246	74.8	9.7
1964	14.117	7,059	75.9	9.3
1965	13.734	6,867	77.0	8.9
1966	13.343	6,672	78.0	8.6
1967	12.944	6,472	79.0	8.2
1968	12.537	6,269	80.1	7.8
1969	12.122	6,061	81.1	7.5
1970	11.699	5,850	82.1	7.1

[1] Total labor force (men and women 14 years and over) based on medium population projection (15).

This rapid decline of man-hour requirements is, of course, due mainly to the enormous increase of labor efficiency, although also other factors such as the development of higher-yielding and more disease-resistant crops and animals, more effective disease and insect control, application of more fertilizers, etc., play an important part. The increasing efficiency of farm labor can best be measured by the index of farm output per man-hour as shown in table V and graphically illustrated in graph IV.

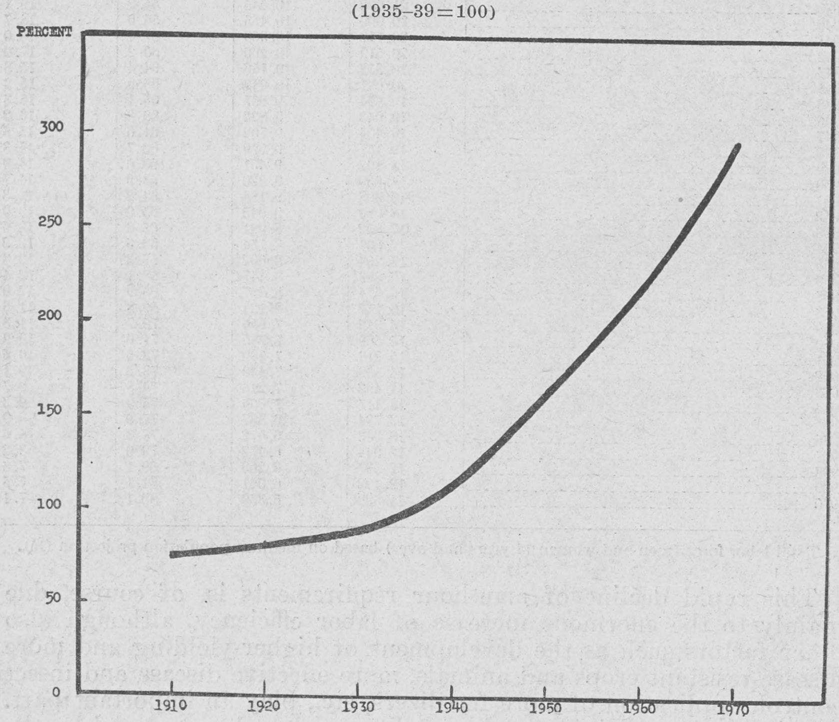
TABLE V.—*Index of farm output per man-hour* [1]

[1935–39=100]

Year	Index	Year	Index	Year	Index
1910	74	1931	93	1952	170
1911	72	1932	94	1953	176
1912	78	1933	86	1954	182
1913	72	1934	82	1955	187
1914	76	1935	96	1956	193
1915	80	1936	88	1957	200
1916	73	1937	103	1958	206
1917	76	1938	106	1959	213
1918	75	1939	107	1960	220
1919	76	1940	112	1961	226
1920	81	1941	118	1962	233
1921	77	1942	127	1963	241
1922	82	1943	125	1964	248
1923	82	1944	130	1965	256
1924	81	1945	136	1966	263
1925	82	1946	144	1967	271
1926	83	1947	142	1968	279
1927	87	1948	157	1969	287
1928	89	1949	156	1970	296
1929	88	1950	164		
1930	87	1951	164		

[1] Index numbers from 1910 to 1948 from Hecht and Barton (16) extrapolated till 1970 according to equation (2).

CHART IV.—INDEX OF FARM OUTPUT PER MAN-HOUR
(1935–39=100)



As we can observe in chart IV, the index of farm output per man-hour shows a steady but moderate increase from 1910 to 1930; in fact, it rose during this 20-year period only 13 points or 0.65 per year. However, from 1930 to 1940 the increase was 25 points or 2.5 per year, and during the period from 1940 to 1950 it rose 52 points or 5.2 per year.[2]

We notice immediately how the index figures gain momentum after 1930 until in 1950 the productivity index was 64 percent higher than during the average of the years 1935–39. This constant increase at a growing slope justifies the extrapolation of the equation until 1970 which shows that the productivity in 1960 will be about two times and in 1970 about three times that of the base period.

To what extent this increase in work productivity is due to mechanization is shown significantly by the type and the total amount of power used per farm worker (17):

[Horsepower]

	1850	1870	1900	1930	1940	1950
Animal power (oxen, mules, horses)	1.8	1.6	1.8	1.6	1.5	0.7
Mechanical power (farm machinery)			.4	10.9	20.5	32.3
Total	1.8	1.6	2.2	12.5	22.0	33.0

If we divide the number of man-hours in agriculture by 2,000 (the average number of hours per farm worker in 1 year), then we obtain a figure indicating the number of workers (operators and hired men) required for agricultural production. As man-hour requirements go down (column 1, table IV), so decreases the number of people that can find gainful occupation in agricultural pursuits (column 2, table IV). While this number was 11.5 million in 1910, it decreased to 9.3 million in 1950, and will be, according to equation (1), about 7.8 in 1960 and 5.9 million in 1970.

However, at the same time as the number of agricultural workers decreases, the total labor force of this country (column 3, table IV) increases as the natural result of the population increase. Consequently the ratio of agricultural workers to all workers declines even more sharply than the absolute figures of farm workers. As we can see in table IV (column 4), it was in 1910 about 30.8 percent of the total labor force, in 1950 only 14.7 percent, and will be, according to equation (1) on the basis of a medium population projection, 10.9 percent in 1960 and only 7.1 percent in 1970. Our Nation which in 1820 was to 71.8 percent occupied in agricultural pursuits and a hundred years ago still to 63.7 percent engaged in agriculture (table II), will find itself in 10 years from now employed in agriculture to a very small degree and in 20 years still less.

The above figures on prospective changes in the composition of our labor force were arrived at by purely statistical methods, namely by mathematical projection of the present trend in agricultural employment into the near future. However, the results obtained by this

[2] This accelerated increase of work productivity is shown by a parabolic curve which is expressed by the regression equation of second order:

$$Y=135.7581-4.42848\ x+0.0803613\ x^2 \quad . \ . \ . \ . \ (2)$$

in which x expresses the time in years starting with 1910 and Y is the index of farm output per man-hour calculated on the basis of 1935–39 equals 100 with dollar values deflated to that prevailing during the base period.

method are so startling and so indicative of profound structural changes in our economic and social institutions that the social scientist who is forced by logical reasoning to accept them, has the bounden duty to ask himself whether these figures are realistic and supported by technological facts. It is at this point where chemical agriculture steps into the picture.

2. THE EMERGENCE OF CHEMICAL AGRICULTURE

When the pioneer fathers settled in the land that was to become the United States, they found good farming country and reaped good harvests. True, they were often plagued by insect pests, plant diseases, and weeds, but since they could not do much to avert such misfortunes, they accepted them as acts of God. However, after crops had been grown for several years, the soil became less productive and thus farmers were forced to move westward to new, untilled lands. But the time came when it was found more profitable and expedient to use such farming practices that would renew tired soils, instead of pushing westward and leaving the depleted land behind.

The new frontiers of agriculture are no more in the West, but lay in the agricultural experiment stations that use the methods of trial and error, in the chemical laboratories that penetrated into the secrets of living matter and into the action of chemicals upon them, and finally in the chemical factories that manufacture those substances needed for the rejuvenation of the soil and the production of a plentiful crop.

If we study all the factors that played important roles in this new scientific form of agriculture, we will find that chemistry occupies the most prominent place. The part that it plays in this development had such far-reaching consequences that a new and special branch of this old science sprang up, known as agricultural chemistry.

The first result of scientific research in agricultural chemistry was the establishment of the specific requirements of plants for such plant nutrients as would produce optimum yields, and the development of a large industry of artificial fertilizers and plant foods. Fertilizer consumption by American farmers increased from about $50 million in 1900 to 149 in 1910, 382 in 1920, 288 in 1930, 261 in 1940, and $892 million in 1950 (18). With the discovery of the trace elements that are essential to plant growth (19), and the development of a complete fertilizer that gives the plant all essential nutrients in one dose (20), this section of agricultural chemistry has come to full fruition.

However much the application of fertilizers increased the output per man-hour of the farm worker, they did it indirectly, namely by tremendously increasing the yield of certain crops. It, therefore, cannot be considered in a strict sense as "chemical labor-saving devices." But the great success of agricultural research and scientific farming methods was a mighty promoter of further research in agricultural science which was then encouraged and supported by the Federal Government.

In 1862 the Morrill Land-Grant College Act laid the foundation for agricultural research and education in the United States. In 1887 the Hatch Experiment Station Act provided funds for agricultural research. In 1906 the Adams Act made means available for special investigations. In 1925 the Purnell Act provided funds for economic and sociological studies in American agriculture. In 1935 the Bankhead-Jones Act supported the various State agricultural experiment stations. And in 1946 the Research and Marketing Act provided additional funds for research in agricultural production and distribution of agricultural products.

This great emphasis which the Federal Government put on agricultural research brought results that could hardly have been imagined when the research program was initiated. Until about 10 years ago the main effort of agricultural research was directed toward exploration and promotion of normal physiological processes in plants and animals. Then the discovery was made that a substance which had just been isolated from human urine, indole-3-acetic acid, has the ability to change the rate and type of plant growth. Subsequently many other substances were isolated and produced synthetically that stimulate plants in different ways and, therefore, called auxins or growth regulators (21).

It now became clear that plants, just like animals and humans, are sensitive to certain chemical substances that can be readily produced in the laboratory or factory, and that by means of these substances life processes can be altered or interfered with such as to produce abnormal, but economically more desirable, results. The most spectacular of these growth regulators is 2,4–D (chemically called 2,4–dichlorophenoxy-acetic acid) which in 1943 was patented because of its growth-stimulating property. While it is true that this chemical when applied in extremely small amounts (about one millionth of an ounce) to a small part of a plant makes it grow much faster than the untreated part, about 2,000 times this amount will cause the plant to burn up its food supply and to die within 1 to 3 weeks after treatment.

The most important property of 2,4–D, however, is that, while it is highly toxic to broad-leaved plants, it has no effect upon grassy plants. Since this latter group includes the cereals and many of the forage crops, it comes like an answer to an ardent prayer of many farmers whose fields have become infested by noxious weeds, the prayer for a weed killer which would destroy only the undesirable vegetation, but leave the cultivated plants unharmed. The problem of destroying all plant growth on a given area is relatively simple. There are many efficient herbicides that would do the job. On the other hand, the selective destruction of one plant species without harming other ones has always been the most difficult problem in agriculture which before the discovery of selective herbicides such as 2,4–D could only be solved by the back-breaking and laborious job of chopping, hoeing, or hand pulling of the noxious weeds.

The discovery of the herbicidal properties of 2,4–D stimulated intensive research into the use of a wide variety of chemicals for weed control and during the last 5 years herbicidal investigations spread all over the country. It was found that 2,4,5–T (chemically called 2,4,5-trichlorophenoxyacetic acid) surpasses 2,4–D in efficiency and that IPC (isopropyl-phenyl-carbamade) and TCA (sodium trichloroacetate) show selective herbicidal action against grasses, especially the most noxious Johnson grass, while leaving broad-leaved plants unharmed. Also many other compounds have been tried successfully as selective herbicides and thus have brought about a new era in agriculture as work, formerly done by hand, and later by machine, is now accomplished by the application of chemicals. Since these chemicals are carefully selected and even made to order to serve specific purposes, as much as machines are constructed to carry out a certain mechanical operation, we are justified in calling this new agricultural epoch into which we are now entering "chemical agriculture."

Chemical methods are not restricted to the eradication of noxious weeds. Their applicability as labor saving devices in agriculture and horticulture is much more comprehensive. Indolebutyric acid applied to unfertilized ovaries of tomato plants brings about the production of seedless fruits which often surpass the pollinated ones in size and flavor. This is an outcome especially valuable in the growing of tomatoes in greenhouses where hand pollination of flowers is a most laborious and not always satisfactory job.

Growth regulators are also of great value to the plant propagator since cuttings of such trees as apple or pine which can be rooted only with great difficulty can be stimulated to produce sturdy and vigorous roots faster than under normal conditions. It is amazing how small amounts of the growth-regulating substance are able to bring about this desired effect.

Another application of growth promoting substances is the prevention of premature shedding of fruits. Since the normal shedding of fruits is associated with reduction in the supply of growth substances, the shedding response may be retarded by application of indoleacetic acid to the organ whose fall is to be delayed (23).

Another application of growth regulating substances such as naphthaleneacetic acid and its sodium salt consists in the thinning of fruit trees which is essential in order to avoid the tendency toward biennial bearing and to obtain fruits of larger size and better quality. In some sections, particularly the Western States, hand thinning represents the greatest single cost in apple growing. In the State of Washington it requires usually 100 to 175 man-hours per acre in order to obtain satisfactory annual crops of good size and quality. Therefore, in order to save manpower in the Pacific Northwest five to twenty thousand acres of apples have been thinned by chemical sprays which were applied to all commercial varieties (24) during the last 3 years. The possibilities of using chemical thinning sprays also to pears and peaches are presently being explored.

Another artificial interference with the normal life process of fruit trees is the inhibition of premature blossoming. In areas subject to late spring frosts it is often the cause of millions of dollars damage. Spraying of the tree with a solution of the hydrazide of maleic acid delays the blossoming process and thus prevents premature blossoms being killed by frost.

An interesting application finds growth regulators in pineapple plantations. Growers of pineapple find it economically undesirable having all their fruits ripen at the same time with processing facilities thereby taxed to capacity. Since it has been found that pineapples can be made to flower and ripen at an early date by spraying them with either 2,4–D or naphthaleneacetic acid, it is possible for the pineapple growers to make the fruits mature at different dates, and stagger the harvest and processing period according to available facilities. The saving in man-hours by proper planning of harvest time is obvious (25).

When leaves interfere with the speedy or mechanical harvesting of crops, it appears desirable to apply chemicals that would destroy the foliage without injuring fruits. A great number of such chemical defoliants have recently been discovered and their application has proved of enormous economic importance to cotton production. These defoliants not only facilitate the operation of mechanical cotton pickers, but also increase the speed of hand picking up to 100 percent. In addition to the great labor saving involved, the application of defoliants have several other important advantages: (1) The increased exposure to the sun and to the drying action of air movement opens mature balls much faster; (2) boll rot and fiber and seed deterioration are checked; (3) the absence of leaves robs mosquitoes and other annoying insects of cover and broods of food for overwintering; (4) boll weevils leave defoliated fields immediately and thus defoliation is of great aid in insect control.

Thus it is not surprising that cotton defoliation which was unknown in 1946 has spread throughout the Cotton Belt in very short time and in 1950 an estimated 1.5 million acres or 8 percent of the total cotton acreage were defoliated. The first efficient cotton defoliant, calcium cyanamide, requires heavy dew and is, therefore, applicable only in the humid areas of the South and Southwest. Another more recently developed defoliant, sodium cyanamide, is not dependent on high leaf or atmospheric moisture and thus has opened the cotton areas of Texas and California to defoliating practices. And there are still more and ever stronger defoliants being developed such as sodium monochloroacetate, potassium cyanate, pentochlorophenol, the latter showing an especially strong tissue action (26). It should be pointed out that none of the defoliants so far developed showed any injurious effect upon cotton fiber, cotton seed, cotton seed oil, or cotton seed meal. Moreover the decomposition products of some of them, for instance calcium cyanamide has added to the calcium and nitrogen supply of the soil. Progress in application of defoliating sprays and dusts (to be discussed in a later section of this paper) will further promote the adoption of this new and most efficient labor-saving device and we may expect a further very large expansion of defoliating practices in cotton production in a very few years.

In the case of cotton it appeared expedient to destroy only the leaves of the plant in order to facilitate harvest. In the case of potatoes, however, it is fast becoming a general practice to destroy the entire plant above the soil, to make the harvesting of the tubers less time consuming and more efficient. Formerly potato vines were destroyed by mechanical means or by flame which are time-consuming practices, while the application of very efficient nonselective herbicides such as various dinitro compounds (for instance 4,6-Dinitro-ortho-cresol) is now being used to kill quickly the green parts of the potato plant. Apart from its great labor-saving advantage for both manual and mechanical digging of the tubers, the destruction of the tops makes the tubers firmer and gives them a tougher skin which is less liable to be damaged during harvest and storage. And most important of all it destroys the fungus Phytophtora infestans which causes the late blight originating in the leaves and, if not checked in time, may proceed to cause decay of the tubers after harvest.

The plant physiologists have gone already a long way in a very short time, in making plant-growth-regulating substances and other chemicals interfering with the normal life processes of plants, available for more efficient and more economical crop production. Animal physiologists have, however, just started to use animal growth regulators purposefully for the increased production of animal products, especially in meat supply. Already the initial discoveries made in this field through intensive scientific research, especially by scientists at the agricultural experiment station in Beltsville, Md., are so startling that they deserve serious examination not only from the general viewpoint of food and nutrition, but also from the very special one of man-hour requirements. This is particularly important because animal husbandry and the production of animal products is the largest user of man-hours in American agriculture.

The growth of animals like the growth of plants is dependent upon certain growth-regulating factors. However, while most plants are self-sufficient in synthesizing their own growth substances, this is not, or not sufficiently, the case with most of the domesticated animals. It was known for some time that poultry and swine require a certain animal protein factor for early growth and satisfactory reproduction. But what this missing nutritional link was remained a puzzling mystery until it was found to be vitamin B_{12} which the research workers at Beltsville demonstrated to be identical with the growth and reproducing factor for chickens (27). The fact that this new vitamin could be commercially obtained through bacterial synthesis led not only to its easy availability but also to a new discovery in the field of animal nutrition of no less fundamental importance than that of the growth factor. The incidental presence of the antibiotic aureomycin in one of the commercial vitamin supplements led to the realization that in addition to vitamins also certain antibiotic substances that recently had gained such prominence in medicine are able to stimulate the growth and reproduction of pigs and chickens.

The lack of the animal growth factor in soybean meal (the most nutritive, most abundant, and least expensive protein supplement for animal feeds) limited the expansion of swine and poultry production. Now the discovery of vitamin B_{12} and of antibiotics promises an ample meat supply, and incidental to the faster growth and reproduction of the animals, a proportionally smaller amount of man-hours in feeding and tending them. Because of the extraordinary efficiency of the antibiotics their use is also very economical. For instance 2 grams procaine penicillin per 1 ton of chicken feed at an additional cost of $1 produces broilers of 3 pounds in 9 weeks instead of 11 weeks feeding time. Calves grow 10 percent faster and become 10 percent heavier at the same feeding ratio when minute amounts of antibiotics are added to the normal diet (28).

The stimulation of the animal's growth and reproductive possibilities by chemical and biochemical means is an entirely new and very promising field of scientific research which may have far reaching consequences in the field of nutrition and agricultural economics. It opens a new avenue in chemical agriculture, so new in fact, that at this time we can hardly evaluate it effects upon manpower utilization of farm labor.

We have seen how within the last 10 or 15 years chemistry has changed agricultural production and how a new labor-saving farm economy is in the making. But we cannot close this chapter on "chemical agriculture" without mentioning also the great progress that has been made in the use of chemicals for the eradication of fungus diseases and the extermination of insects directly injurious to plants and animals, or indirectly as transmitter of disease causing bacilli and viruses. Although the application of chemicals for pest and disease control cannot strictly be termed a labor-saving device, the indirect results upon the agricultural labor market are bound to be no less far reaching than the direct action of agricultural chemicals. For in the end it makes, economically speaking, little difference in the volume of man-hour requirements whether chemicals reduce farm work by way of higher productivity or by prevention of losses to crops and livestock. As a rule both ways will be practiced to obtain optimum production in regard to costs, soil and climatic conditions, market outlook, and prices, and they are so intricately interconnected in actual farm operations that their artificial isolation would be quite unrealistic from an economic point of view.

The annual losses to agriculture caused by insects are estimated to be as much as $4 billion per year (29). Greatest loss, estimated at $600 million, was due to the action of weevils and moths in stored grain. Next comes the damage to livestock, estimated at $500 million. Corn borer and corn earworm caused damage of $237 million, and cotton insects $153 million. This explains the growing demand for more and better insecticides and the most intensive and vigorous research in this field. While this research work which was strongly supported by the Federal Government, brought many spectacular results, the most significant discovery was that of DDT (chemically called dichlorodiphenyltrichloroethane). In 1942 only a small amount of this chemical product was available. Its military significance as an effective agent against disease-spreading lice and mosquitoes caused its rapid adoption and an almost unbelievably fast expansion of production. After the Second World War it became available for civilian consumption and was avidly taken up by progressive farmers as a long-sought agent against numerous insects that had caused tremendous damage to crops.

However, DDT was not effective in all instances. One significant exception was its failure to kill the boll weevil which has been the cause of great damage to the cotton growers of this country. Here another chemical substance whose insecticidal action had been discovered in France in 1941, namely benzene hexachloride (chemically called hexachlorocyclohexane has shown great effectiveness, but its application is limited because of its disagreeable odor (30).

Another chemical which until 1938 had only been considered a chemical curiosity, namely, phenothiazine (chemically called thiodiphenylamine) was found to possess remarkable anthelmintic activity in ridding farm animals, especially horses, cattle, sheep, and goats, of gastrointestinal parasites such as roundworms. Sodium fluoride, a cheap and readily available chemical, proved to be very effective in destroying large intestinal worms or ascarids in swine, thus making it possible to control the most widespread and most injurious parasites affecting swine (31).

No less severe than the damage caused to agriculture by insects and nematodes is the loss caused by fungi and plant diseases. Most of the fungicides are based upon copper and sulfur. Recently, however, synthetic organic fungicides have gained ever more importance, thus relieving the demand for these two critical elements of strategic importance. Mention should be made only of chloranil (tetrachloroquinone), 2,3-dichloro-1,4-naphthoquinone, pentachlorophenol, and dithiocarbamates (32).

An incidental but very important "labor-saving effect" of the increased use of insecticides and fungicides is the eradication of many human diseases in rural areas transmitted through animal parasites or fungi. It has been estimated that malaria alone is the direct or indirect cause of over one-half of the entire mortality of the human race. With its powerful accomplice, the hookworm, it has been a major factor in reducing human efficiency and retarding economic progress, especially in parts of our own Southern States (33). The eradication or substantial reduction of many communicable diseases together with improved nutrition must have resulted in greater productivity per man-hour since a healthy, sturdy, well-fed body and alert mind can certainly do better work than a disease-ridden, weak, malnourished body and dull mind. This greater efficiency must by itself, apart from gains made through mechanization and rationalization of agriculture, be the cause of "labor saving" and thus accentuate technological displacement effected by technical progress. However much this incidental but very important consequence of chemical agriculture must be acclaimed from a human and social point of view, it deserves serious consideration in any study that tries to evaluate the effect of recent developments in agriculture upon demand for farm work.

We have seen the efficiency and versatility of chemicals in many important fields of agricultural production. They are able to increase and improve the crops and animal products. They are being used to protect fruits and vegetables from damage during transit and storage, to hasten the ripening of fruits or to delay the blossoming of trees, to control insects, nematodes, fungi, and plant diseases. And yet science has barely scratched the surface in its exploration of chemical farming tools. Hundreds of new chemical compounds of potential usefulness are synthesized and tested every year. Thousands more are waiting for experimental tests and new uses for old chemicals are being constantly developed (34). To what extent future discoveries in chemistry, plant physiology, microbiology, entomology, and animal husbandry will hasten the spread of chemical agriculture, nobody can predict. But the already known discoveries and adopted new farming practices are sufficient to foretell radical changes in American agriculture in the near future.

In the following chapter an attempt will be made to evaluate the effect of these changes upon farm management in general and labor economy in particular.

III. Farm Management and the Use of Chemicals in Agricultural Operations

1. THE PRODUCTION OF AGRICULTURAL CHEMICALS

Nothing illustrates better the rapid increase in application of chemical substances for agricultural purposes than the growth rate in the manufacture of agricultural chemicals proper, as distinct from fertilizers, manifested during the last decade. In order to promote the use of their products and protect their special interest, 12 chemical manufacturers banded together in 1933 and founded the National Agricultural Chemicals Association, with headquarters in Washington, D. C. At that time about 100 million pounds of agricultural chemicals, valued about $80 million, were manufactured. In 1951 the NACA has a membership of 130 companies, which in 1950 produced a total of more than 1,000 million pounds diverse agricultural chemicals, at a value of about $250 million at the manufacturer's level. Since exports of agricultural chemicals were, with the exception of copper sulfate and DDT, rather small, this increase of production reflects the consumption trend of agricultural chemicals in the United States.

However impressive this figure may appear, it dwindles into insignificance if we consider the potential market for agricultural chemicals in the United States on the basis of the damage done by various pests which these chemicals could successfully eradicate. Losses caused by insect pests are estimated to be as high as about $4 billion, and losses due to fungi and plant diseases no less (35). Recent estimates of total weed damage are as high as $5 billion per year (36). Thus, about $13 billion total damage accrues annually to our agricultural production, which in 1950 had a total dollar value of 31 billions in cash receipts and home consumption. Consequently, the total damage caused to our agriculture by insects, fungi, plant and animal diseases, and weed infestation was about 42 percent of the value of the gross production in 1950. With an average hourly wage for farm workers of 70 cents, this loss is equivalent to 18,750 million man-hours or to the employment of 9,285,000 persons, while the actual number of persons employed was about 9,320,000. In this figure of total damage is not included the money equivalent of damage done to humans through fungus or insect-borne diseases, hay-fever-producing and otherwise poisonous plants, or diseases transmitted by the consumption of infected animal products. Scientists agree that a great part of all these losses could be averted by systematic and comprehensive use of insecticides, fungicides, rodenticides, and herbicides.

Although statistical data on the production of agricultural chemicals are very sketchy and in some instance unobtainable when the respective chemical is used also for other purposes, table VI will attempt to give a picture of the development of the important agricultural chemicals. An interesting feature disclosed by the table is the contrast between the steady increase in the production of inorganic agricultural chemicals and the almost explosive expansion that took place in the field of synthetic organic agricultural chemicals, which started only in 1944 with the manufacture of a small amount of DDT. Now the production of agricultural chemicals has become a vital factor in our national economy, as these products are indispensable for the protection of our crops and livestock and the health and welfare of our entire Nation. Its future potential, however, is not indicated by what it does but by what it could accomplish.

95402—52——4

TABLE VI.—*Production of agricultural chemicals* [1]

[In thousands of pounds]

Year	Calcium arsenate	Lead arsenate	Copper sulfate	Ground sulfur (log t)	Benzene hexa-chloride	DDT [2]	2, 4-D [3]	2, 4, 5-T [4]
1940	41, 349	59, 569	134, 032					
1941	56, 136	26, 912	170, 978					
1942	84, 136	63, 571	210, 400					
1943	74, 854	73, 555	178, 200					
1944	44, 350	90, 705	205, 200	580, 000		9, 626		
1945	25, 644	70, 522	251, 000	600, 000		33, 243	917	
1946	35, 393	56, 667	255, 800	620, 000		45, 651	5, 466	
1947	46, 946	30, 187	178, 200	740, 000	8, 197	49, 600	5, 629	
1948	27, 234	24, 630	193, 400	800, 000	18, 382	20, 240	21, 889	
1949	16, 006	17, 866	158, 000	740, 000	27, 937	43, 700	19, 106	
1950 [5]	50, 000	39, 500	174, 600	800, 000	76, 670	77, 872	14, 156	1, 100
1951 [5]	66, 600	39, 200	213, 900	800, 000	84, 200	77, 200	21, 800	2, 364

[1] National Production Administration, Division of Agricultural Chemicals.
[2] Dichlorodiphenyltrichloroethane.
[3] 2, 4-dichlorophenoxyacetic acid.
[4] 2,4,5-trichlorophenoxyacetic acid.
[5] Estimates.

In addition to the agricultural chemicals mentioned in table VI, we ought to specify a host of newer synthetic organic chemicals that are now being used to ever larger extent in veterinary medicine, animal husbandry, horticulture, and crop production, but will enumerate only a few more significant products. Phenothiazine is used as a powerful anthelmintic agent to rid farm animals of all kinds of worms that cause tremendous damage. Chloropikrin, methyl bromide, ethylene oxide, carbon disulfide, and trichloroethylene are used as fumigants for the destruction of insects in soil or stored grain. Chlordane, toxaphene, aldrin, and parathion are modern insecticides of great effectiveness in specific applications (37). In addition to the older copper, mercury, and sulsulfur and other inorganic compounds, chloranil, pentachlorophenol, dithiocarbamates, and thiuram sulfides have gained increasing importance as effective fungicides (38). In addition to 2, 4–D and 2, 4, 5–T increasing quantities of dinitrophenols, PCP (pentachlorophenol), TCA (trichloroacetic acid), calcium cyanamide, ammonium sulfamate, and IPC (isopropyl phenylcarbamate) are used as herbicides (39).

The farmer needs both an adequate supply of the essential agricultural chemicals and the assurance that he is getting the most efficient and most economic ones according to the present status of scientific knowledge. The United States Department of Agriculture established in 1951 a special section for agricultural chemicals within the Office of Materials and Facilities of the Production and Marketing Administration, whose main function is to estimate the prospective requirements of agricultural chemicals in all fields of application under special consideration to those which might be in short supply. The National Production Authority, on the other hand, created within its Chemical Division a special section of agricultural chemicals to integrate their manufacture into the totality of chemical production. Although agricultural chemicals compete in many respects for raw materials and plant facilities with chemical products essential for military purposes, all efforts are made to let the farmer have all chemicals he requires.

2. THE APPLICATION OF AGRICULTURAL CHEMICALS

The spectacular development in all fields of agricultural chemicals would have been impossible without constant improvement of appliances for their economic and efficient application. From simple hand-operated sprayers of solutions or emulsions of the insecticidal and herbicidal substances as are still being used on small farms or for horticultural purposes developed all kinds of power sprayers that are mounted on wheels. Modern speed sprayers have increased application efficiency by reducing labor costs, and tractor-drawn ejectors allow the application of soil fumigants on a field basis. The greatest discovery, however, in the field of application equipment was the principle of low-gallonage spraying, which permits uniform effective coverage of 1 acre with insecticidal or herbicidal sprays by the use of less than 5 gallons of spray carrier as compared with 50 gallons or more for older type sprayers (40).

The invention of the low-gallonage sprayer greatly promoted another revolutionary change in agricultural practice; namely, the use of the airplane for farming. It is of great significance that aerial agriculture emerged at the same time as chemical agriculture and that both aided one another mutually to such an extent that at the present time it is estimated that of the 1 billion pounds agricultural chemicals applied to our farms during the last year about half was cast down from the air (41).

Airplanes have a tank capacity of about 150 gallons, and no more than 3 acres could be sprayed per load with the old-type equipment which was quite uneconomical. The modern low-gallonage sprayer on the other hand, allows a coverage of 30 or more acres with each load and thus makes the airplane as an instrument in chemical agriculture not only economical but increasingly more efficient than all kinds of ground operations. But when we consider all the advantages which the airplane has in many farm operations over manual or mechanized ground equipment—and this not only in the application of agricultural chemicals but also in seeding, artificial pollination, cattle ranching—we will not be surprised at its rapid development especially in the central plains and the far West, but see the future tremendous possibilities of farming from the sky (42). Most spectacular is the effectiveness of the airplane in terms of time and labor savings in various farm operations, as shown by the following figures:

Labor saving in aerial operations

Average time required per operation	Manual operation, 100 acres and 5 unskilled workers	Aerial operation, 100 acres, 1 pilot and 4 unskilled workers
	Hours	*Minutes*
Rice seeding	30	30
Cotton dusting	60	30
Cotton defoliating	60	30
Fertilizer application	30	30
Weed control	60	30
Pest control	60	30

In addition to labor economy the time factor might become in some instances of decisive importance. It not only allows the farmer to apply the chemical in the right moment but also enables him to do it so fast that his crop when invaded by ravaging insects can be saved, where it would be destroyed before the much slower ground operations could be completed. Furthermore, great losses are often due to destruction of cultivated plants by trampling down in ground operation with animals or tractors. Such losses are naturally avoided by aerial operations. Finally, many areas that are not accessible to ground equipment because of the terrain or softness of the soil can now be cultivated from the air, which saves a lot of time and increases the productive season.

The equipment for the application of chemicals from the air can be moved rapidly from one place to another, enabling a relatively small amount of machinery to give efficient protection against emergency invasions of pests over a wide area. With proper service organization considerable savings can be made in equipment required to insure adequate protection at any one place. The high mobility of planes and equipment allows a continuous use throughout the growing season.

After the Second World War, surplus planes and former military pilots were available at low costs and trained pilots returned from military duty. The planes, however, were not particularly designed for agricultural work nor were the pilots familiar with the special requirements of agricultural operations. The intervening time has been well used in training ever more pilots for agricultural work and adapting airplanes for farm operations. This development culminated in the spring of 1951 with the construction of the AG–1, the first airplane built especially for agricultural operations such as dusting and spreading insecticides, broadcasting seeds and fertilizers from the air. The plane was constructed under contract with the United States Civil Aeronautics Administration by the Aircraft Research Center at the Texas Agricultural and Mechanical College. The AG–1 can carry 1,200 pounds of insecticides and operate 3 hours without refueling. It flies low and slow, can make tight turns at the end of the field, take off and land at a very rough runway. Many further devices are installed to make the plane as safe as humanly possible. In spite of its high degree of adaption to agricultural operations the AG–1 will probably be surpassed in its suitability for farm work by helicopters that are now ever more used in agriculture, and only the future can tell to what degree of efficiency and economy aerial agriculture will develop (44).

The universal acclaim which the airplane as a farming tool has found all over the United States is reflected in quotations obtained from the heads of agricultural or aeronautical commissions of many States in the Union. For instance the director of the Aeronautic Commission of the State of North Dakota, Harold Vavra, writes:

> The acceptance of aerial crop spraying and dusting has increased very rapidly since 1949. During 1950 and 1951 North Dakota had 180 airplanes in use for this type of work. * * * It is not uncommon for aircraft to spray 60 or 70 acres an hour compared with 100 acres a day for a tractor-drawn ground sprayer. Many farmers claim that the use of aerial spraying is paid for by the grain saved from being tramped down by the tractor.

The commissioner of agriculture of the State of Minnesota, L. L. Schroeder, sums up the advantages of aerial agriculture by saying:

> The greatest advantage of aerial application rests with the speed, timing, ability to make application without damage to the crops, and the ability to make

it regardless of the condition of the terrain. We fully expect the demand for this type of service to continue to increase, and particularly if more effective chemicals become available.

The director of the Aeronautics Commission of the State of Montana, Frank W. Wiley, writes in his letter:

At present there are approximately 1,100 aircraft operators in Montana with approximately one-half million population. The aircraft is extremely valuable to the farmer and rancher particularly in the wintertime when other means of transportation are not practical.

The director of the Division of Aeronautics of the Industrial Development Commission of the State of Kansas, Glenn Taber, writes:

In 1949 about 2,000,000 acres of wheat were sprayed by airplane. The 1951 season is just finished and we estimate that the figure is about 1,500,000 acres. It would have been higher had it not been for the floods * * * My personal opinion is that we have only scratched the surface when it comes to using the airplane for farming operations * * * With advances in agricultural chemicals, the field will broaden and we expect to see the day when farming can hardly be done without the airplane. This is especially true in Kansas where fields are large and airplanes come into their own.

The airport engineer of the Department of Public Works of the State of Louisiana, John W. Myers, writes:

Aerial cropping is used extensively on all three of the principal crops grown in Louisiana, that is, rice, sugarcane, and cotton. A large percentage of the rice crop is now planted by aerial methods and after planting deweeded and fertilized by air. The latter two operations were unknown until the airplane came into use, as the fields being flooded, it is impossible to do this work with ground equipment. As to the planting, the airplane is taking the place of ground equipment at a rapid rate and probably will be the only method used within a few years * * * In the past few years a considerable portion of the cane crop has been treated by air methods for the control of cane borers. Cotton was first treated from the air for the control of boll weevils, but this work has been expanded to include the control of other insects and the application of defoliants * * * Farmers report that, because of the labor shortage, it would probably be impossible for them to sustain production without the assistance of aerial croppers, and certainly it has proven to be more economical than ground methods.

The director of the Aeronautics Commission of the State of Mississippi, C. A. Moore, sums up his opinion in these words:

In my opinion the importance of the use of the airplane cannot be overemphasized. It has come a long way in recent years as the use has spread to all parts of the country. As I see it, there is a need for education programs on this work both for aerial applicators and farmers.

The great enthusiasm encountered by the farmers of so many sections of this country for aerial operations in agricultural work explains the rapid increase of the number of aerial operators, companies or private individuals who own one or more planes and do custom work for the farmers. While in 1950 about 1,600 companies and individual operators were flying 5,000 airplanes, in 1951 about 1,800 companies and individual operators are putting about 6,500 airplanes in the field. Of these airplanes 1,172 are equipped for dusting, 654 for seeding, 1,454 for spraying, 455 for fertilizing, 212 for cotton defoliation, while 950 were equipped for either dusting or spraying. In the average 10 pounds of dust or 2 gallons of solution are used per acre for insect or weed control and the service is charged either per acre or per pound, exclusive the price of the chemical which is usually supplied by the farmer, the price ranging from 70 cents to $2 per acre according to circumstances (45).

More recent than the introduction of aircraft into farm practices is another development in agricultural techniques which promises to be of equally great impact upon the use of agricultural chemicals and consequently upon displacement of farm workers. This new method of agriculture consists in the use of coated or pelleted seeds instead of bare seeds for planting purposes. Since time immemorial man has cultivated crops by sowing their seeds or putting them into the soil without any cover or protection against the many hazards they may encounter before, during, and after germination. Because of their extreme smallness many seeds could not be spaced properly as to make the best use of the available space and in many instances many times more plants emerged as could be satisfactorily grown, which in turn makes time and labor-consuming chopping and thinning operations necessary. Many seeds were eaten by birds, insects, and rodents or destroyed by fungi before they had a chance to germinate and others could not develop properly in competition with more vigorous weeds that took moisture and plant food away from the seedlings. The history of agriculture is, therefore, essentially a history of the constant and determined struggle of man to grow the food for himself and his animals in spite of all these hazards which were compounded by those of weather and climate. The idea appears obvious to provide protection for the bare seeds by covering them with a protective coating or enveloping them in a pellet of inert material. But it was not until after the First World War that seed pelletization was tried and not until after the Second World War that it has found commercial application on a larger scale.

A variety of materials has been tried for making pellets and, though some progress has been made to find the ideal pelleting substance, we are still far from this goal and the opinion of experts as to the feasibility of seed pelletization are conflicting. The first firm to produce pellets on a commercial scale was the Processed Seeds, Inc., in Midland, Mich., which moistens the seeds with a hydroscopic adhesive (methylcellulose) and then coated them with a powdered mixture of feldspar and fly ash. Later on the Filtrol Corp., of Los Angeles, Calif., developed the filcoat pellet from a highly collodial aluminum silicate (montmorillonite). By way of pelletization man has it in his hand to create artificially favorable conditions for germination. He can incorporate into the pelletizing material such insecticides, fungicides, and herbicides as may be needed; he can add growth hormones such as indol-butyric acid or stimulants such as inositol or vitamin B_1; he can supply the seedling with fairly large amounts of phosphates and potash to promote thrifty and rapid growth; finally, he can give the pellets certain colors which have recently been found to repel birds, rodents, and insects; and he can save plenty of seeds by using only as many as are needed for proper spacing.

As far as labor saving is concerned, it is obvious that the main saving consists in the fact that many operations such as seeding, fertilizing, spraying, and dusting can be combined into one and that this single operation lends itself better to airplane work than sowing of bare seeds, as the greater size and larger mass of the pellets prevent the seeds from being blown away as in the case of bare seeds. A second labor saving consists in making thinning and chopping unnecessary. In case of vegetable crops such as lettuce, cabbage, broccoli, tomatoes, carrots, onions, etc., man-hour is saved as no transplanting is necessary. And so we may expect that in the not-too-distant future many of the row crops requiring considerable hand labor will be grown without any labor except for seedbed preparation and harvesting (46).

The use of pelletization for range crops and forest reseeding has been the object of numerous trials by Government agencies and private corporations. However these trials have not fulfilled the overoptimistic expectation which the general public nurtured for this spectacular new method (47). Much more intensive and comprehensive research is needed before a final judgment can be made as to the future potentialities of coated or pelletized seeds; however, if the idea of pelletization can be realized economically in large-scale application it will further revolutionize agricultural technology. Finally the successful synthesis, scientific testing, and experimental production of a soil-conditioning polyelectrolyte, called krilium, the result of 10 years' research work carried out by the Monsanto Chemical Co., promises to become a further step forward in chemical agriculture. Krilium, the sodium salt of hydrolyzed polyacrylonitrile, is from 200 to 1,000 times more efficient than peat moss in promoting soil stabilization, aeration, water retention, and plant growth, and thus could play an important part in agricultural production and erosion control.

3. LABOR SAVINGS IN FARM OPERATIONS THROUGH AGRICULTURAL CHEMICALS

In order to evaluate the over-all effect of the chemicalization of agriculture on total man-hour requirements, employment opportunities, and technological displacement of farm workers in the near future, one would have to classify the total agricultural production according to enterprises and then divide each production group into its individual operations. Once the man-hour requirements for each individual farm operation have been established, one would have to calculate those labor savings that could be obtained through the application of chemicals. However, even such a painstaking and detailed investigation would be quite unrealistic since chemicals do not act by themselves but only in connection with agricultural machinery and thus their effect upon increased productivity cannot be isolated from other factors that act in the same direction. The sharp rise in crop production, for instance, which we could observe during the last 10 years, and which was obtained with decreasing labor expenditure, was only partially the result of application of more and better chemicals, but to a greater extent due to expanded use of fertilizers, improved seeds, especially hybrid corn, more effective farm practices, and, above all, progressing mechanization (48). On the other hand, mechanization, for instance, in cotton harvesting, would not have been possible without discovery of defoliating agents nor could the hybridization of cotton have brought such spectacular results without simultaneous chemical protection against weed infestation and cotton borer. Under such circumstances it would be rather arbitrary to state exactly to what extent productivity increases are due to chemicals and to what extent to other factors nor would it be justifiable to make definite predictions as to the result of increased application of chemicals upon the farm labor market without taking into consideration simultaneous and interdependent productivity increases that are to be expected in the process of increasing mechanization and rationalization of agricultural production. Furthermore, the isolation of chemical factors under the assumption that other factors remain unchanged would have but a very dubious theoretical value, while for the purpose of devising the proper labor policy to meet the problems of technological displacement the total effect of all prospective labor-saving devices upon farm labor requirements will have to be evaluated.

With these limitations we may well look into the more important farm operations and inquire what effect the introduction of chemical methods of agriculture will have upon the prospective gains in productivity. However, the mere establishment of the total or potential productivity increases does not indicate the actual decrease in man-hour requirements and employment opportunities in agriculture; moreover, some assumptions will have to be made as to the rate of adoption of new farming methods which in turn depends mainly upon economic factors, especially demand and price of agricultural products. Having stated this second limitation and stressed the many "ifs" that naturally qualify any prediction of future events, we feel nevertheless bound to draw attention to the social and economic consequences which chemicalization of agriculture may have in store within the frame of technological progress not only in agriculture but also in all the other activities of man.

Such task requires a high degree of simplification of the rather complex and integrated structure of our agriculture and thus it will not be easy to avoid all pitfalls of oversimplification. However, not having any better way of a partly descriptive and partly statistical approach to the solution of this problem, we start with the labor requirements for the important sections of agricultural production as shown in table VII (49) which has been extended through 1950 (50).

TABLE VII.—*Labor requirements for farm work in million man-hours, by enterprises* [1]

Enterprises	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950
Milk cows	3,474	3,515	3,517	3,479	3,446	3,315	3,212	3,040	2,953	3,013
Other cattle	689	743	757	774	760	742	756	730	758	779
Hogs	531	632	750	599	559	556	556	546	577	610
Sheep and wool	263	265	247	222	210	196	173	171	162	159
Poultry	1,013	1,114	1,252	1,257	1,260	1,199	1,136	1,106	1,107	1,151
Horses and mules	944	919	897	862	820	766	699	640	579	528
Corn	2,323	2,326	2,329	2,283	2,121	2,106	1,932	2,040	1,991	1,893
Other feed grain	600	622	567	568	537	523	450	496	449	486
Hay	1,041	1,093	1,029	1,006	1,051	953	931	919	892	925
Cotton	2,177	2,388	2,138	2,142	1,730	1,705	2,113	2,523	2,648	1,727
Tobacco	556	622	631	834	864	980	933	787	824	806
Wheat	432	377	359	418	425	410	444	427	426	346
Other food grain	89	96	88	78	77	70	73	72	68	56
Sugar crops	180	206	167	161	181	189	188	155	153	173
Truck crops	1,127	1,162	1,136	1,191	1,190	1,288	1,185	1,207	1,215	1,215
Vegetables other than truck crops	327	325	392	330	315	329	280	283	267	259
Fruits and nuts	771	764	718	764	743	804	785	758	766	766
Oil crops	243	383	409	339	344	330	354	346	292	335
Other crops	217	217	217	217	217	217	217	217	217	192
Farm maintenance	3,023	3,159	3,136	3,115	2,997	2,962	2,918	2,928	2,907	2,744
All farm work [2]	20,149	21,057	20,910	20,768	19,976	19,769	19,454	19,520	19,380	18,292

[1] (49).
[2] Totals deviate slightly from table IV, which have been smoothed out to show the secular trend.

(a) Livestock production has shown smaller productivity gains than crop production and is now demanding an ever-increasing share in the farmer's time and in man-hours of hired hands. While spectacular improvements in the efficiency of crop production have led during the last decade to considerable reductions in man-hour requirements, livestock breeding and production of animal products does not lend itself so well to mechanization and "chemicalization" as is the case with most of the crops. The main reason is that crop production can be highly centralized, organized, and rationalized, while animals require a great deal more of regular day-to-day routine work, attention to detail, and individual handling. Nonetheless, also the animal industry of this country showed remarkable gains in productivity partly through mechanical and partly through chemical methods which permitted a tremendous increase in animal products without corresponding increase of farm labor.

In the dairy industry the most interesting field of "chemicalization" is the dilution of bull's semen from 40 to 100 times and the preservation of its viability for a time long enough to inseminate artifically 40 to 50 cows. While normally a good breeding bull may be siring about 40 cows, artificial insemination allows the siring of about 2,000 cows per year by one single bull. The formulas for the semen diluent are constantly improved and presently glucose, galactose, sodium phosphate, potassium phosphate, gum, lecithin, water, and sulfa drugs are used in accurate dosages to insure fertilization. Of the 24.6 million dairy cows in this country in 1950 only 2.8 million were enrolled in artificial breeding associations (51) or about 11 percent. Since the dairy herds are usually rather small and scattered all over the country, it will take a great deal of organizational work to increase the ratio of artificially inseminated cows. However, since this type of breeding offers such great advantages in breeding efficiency and in saving of food and labor for breeding bulls, there is no question that it slowly will spread over the entire country, contributing to man-hour saving and technological displacement of farm workers. In no other field of animal breeding has artificial insemination found so much practical application than in the breeding of dairy cows, but it seems to be reasonable to assume that upon the development of suitable inseminating practices and dilution formulas also sheep, hog, and horse breeding will avail itself of these modern techniques with a consequent further increase of productivity and reduction in man-hour requirements (52).

The labor needed for performing the milking operations alone is tremendous in total. While in 1943 an average of 6 million man-hours per day or more than 2 billion man-hours per year were needed only for the milking operation to produce about 118 billion pounds of milk, in 1950 an average of 4.6 million man-hours per day or about 1.67 billion per year produced about 120 billion pounds of milk. Thus in 1943 labor for milking amounted to about 10 percent of the total labor needed for all farm operations, while in 1950 milking still required about 9 percent of the total farm labor—this in spite of the installation of 415,000 milking machines which brought the total number of milking machines on farms to 725,000. The reason for this relatively small labor saving is the fact that, while in large dairy herds machine milking saves about 50 percent of man-hours, the percentage becomes increasingly smaller as the size of the herd shrinks and reaches practically zero as the number of cows goes down to five. Since the average number of cows per dairy farm is rather small, progress in this respect will be rather slow. This offers some opportunity for displaced farm workers, especially for older people, since the handling of a milking machine requires only some skill and great care but no great physical exertion. The use of milking machines would not be possible without the availability of a great number of chemicals for cleaning the udder and cleansing of all necessary utensils. The more important of these are in the order of importance: Trisodiumphosphate, sodiummetasilicate, hyperchloride, caustic soda, and quaternary ammonium compounds. In this sense the mechanization of the dairy industry could rightly be considered the result of "chemicalization" of agriculture. However, while the application of chemicals in other fields of agriculture resulted in substantial savings of man-hours and is bound to contribute even more in future to technological displacement of farm workers, as far as dairy farming is concerned, the introduction of modern production methods will only take care of the additional labor demand caused by the expected very large increase of consumption of milk and other dairy products.

Next to cow's milking, poultry farming, that is the production of chickens and eggs, is the most labor requiring branch of animal industry. Like dairy farming, it requires a great deal of attention to detail and daily routine work which does not lend itself so easily to mechanization as crop production. Nonetheless, great progress has already been made in labor efficiency in those specialized poultry farms that are more "food factories" than agricultural enterprises proper (53). In order to achieve even more efficiency they specialize either in egg or broiler production, taking all advantage of recent discoveries in poultry nutrition, genetics, and veterinary medicine. Chemicals play an important role in keeping the hatcheries, incubators, and laying houses clean with the use of a minimum of labor, and they increase the labor efficiency also indirectly by preventing the outbreak of such disastrous epidemics as fowl typhoid, pullorum disease, Newcastle disease, etc. The recent discovery of the effect of vitamin B_{12} upon growth and reproduction and of vitamins upon better utilization of feed promises to become an additional factor in increased productivity in poultry farming. However, all these advances will not greatly reduce the labor requirements for chicken and egg production.

As far as other branches of animal industry are concerned chemicals will increase the labor efficiency by destroying the carriers and germs of diseases, stimulating the development of the animals by keeping away irritating insects, improving nutritional value of fodder through added trace elements, vitamins, and hormones, keeping the barn clean, and generally improving the sanitary conditions of both livestock and farm workers. This, however, will only lead to a larger output of animal products and to improved quality, but not to a greater employment of farm workers as expected demand increases for animal products would require, were it not for the saving in labor resulting from the application of chemicals and mechanical devices.

(*b*) Corn is the most important crop of the United States. While it is grown in almost every part of our country, it reaches greatest prominence in the Corn Belt of the Middle West. Corn covers a greater acreage, yields a greater dollar value than any other crop, and also requires more labor than any other crop. Because of its great importance for our national economy any increase in productivity of labor in corn production will have a greater effect upon total farm labor requirement than corresponding gains in other fields (54). And here the picture is an entirely different one from that we encountered in animal industry. Hybridization, mechanization, and "chemicalization," that is the use of insecticides, fungicides, and herbicides, has brought a phenomenal increase in yield per acre with a simultaneous decrease of man-hour requirement, as a result of which productivity has more than doubled:

Productivity increase in corn production 55

	1910–14	1915–19	1920–24	1925–29	1930–34	1935–39	1940–44	1945–48
Yield in bushels	26.0	25.9	28.3	26.4	22.1	25.0	32.0	35.2
Man-hours per acre	35.2	34.1	32.5	30.2	28.1	28.0	26.2	23.7
Man-hours per 100 bushels	135	132	119	114	127	112	82	67

While mechanization and hybridization are almost complete in the Corn Belt where more than half of the corn crop is harvested, there is still room for expansion in many parts of the South where corn is grown. Inasmuch as hybrid corn yields 15 to 30 percent more per acre than open-pollinated varieties, a country-wide adoption of hybrid corn will increase the corn crop by about 15 percent and this larger crop will need fewer man-hours for cultivation and harvest, if the same mechanical labor saving devices will be introduced as are now in use in the main corn growing areas.

But the greatest effect on labor requirement in corn production will not be due to further mechanization and expanded use of hybrids, but to chemical farm practices. The most important of these will be the introduction of preemergence weed control by way of 2,4–D or calcium cyanamide. Experiments have shown that, if weeds are permitted to grow, the corn yield will be about 7 bushels per acre, while total elimination of weeds results in a yield as high as 53 bushels per acre (56). Since agriculture began, man has expended much toil in strenuous chopping, hoeing, and cultivating in order to bring weeds under control. This laborious manual and mechanical work can now be eliminated by the simple expedient of applying 1 pound of 2,4–D per acre after the crop has been planted which operation takes with the tractor-drawn power sprayer about 1 hour as compared to 100 hours of manual weeding.

Every year insects and fungi demand a heavy toll which resulted in partial or total loss, and corresponding reduction of average yield per acre. The European corn borer destroyed 314 million bushels in 1949 and 59 million bushels of corn in 1950, while the corn earworm destroyed 70 million bushels in 1949 (no figures for 1950 available). Additional heavy losses are caused by root, stalk, and ear rot due to the fungus *Fusarium* and by smut, a fungus disease caused by *Ustilago zeae*. They can be prevented by the application of modern insecticidal and fungicidal practices.

It is not too much to expect a 50-percent increase in yield of corn only as the result of elimination of losses caused by weeds, insects, and fungi which, when applied to an already 30-percent increased yield effected through hybridization and greater fertilizer application, will cause a 100-percent increase of yield per acre without additional labor requirements. While more corn will be needed as fodder for an expanding animal production, it would be unreasonable to assume that our country will be able to absorb the entire increase in production caused by chemical agriculture. Consequently labor requirements in corn production will further decline and it appears conservative to expect a decrease in man-hour requirements of about 800 million man-hours over a period of the next 10 years equivalent to a technological displacement of 400,000 workers.

(*c*) Wheat ranks next to corn in national importance because it is grown by many farmers, covers a large land area, constitutes the basis of our nutrition, and an important export commodity. While we have not yet achieved such a spectacular success in plant breeding of wheat as was the hybridization of corn, on the other hand, mechanization of wheat production has gone even further than that of corn production. Thus no greater labor savings are to be expected through the application of more efficient farm machinery, while application of more fertilizers and especially of chemical methods of weed and pest control are bound to bring further considerable increases in yield per acre.

Very great are the losses due to weed infestation especially in the drier wheat growing sections where the hardier weeds rob the cultivated plants of scarce moisture and most valuable soil nutrients and fertilizers. According to reliable estimates last year's wheat harvest of 1,027 million bushels could easily have been 10 percent larger, were it not for weed infestations. Mechanical cultivating methods required for weed control are a significant factor in total labor requirement for wheat production and could be eliminated by chemical weed control, especially aerial application of 2,4–D. Additional losses are caused by insects, especially the most destructive Hessian fly, and the wheat jointworm as well as by many kinds of diseases caused by fungi such as smut, rust, rot, and blight. In total it would not be exaggerating to assume an additional 15 to 20 percent potential increase of yield as the result of the elimination of the preventable losses caused by insects and fungi. Dusting and spraying with insecticides and fungicides by airplane would be a most efficient and labor-saving method of achieving this end.

Thus chemical agriculture could bring about a 30-percent increase of wheat production without additional expenditure in farm labor. However, while the wheat production has shown during the last 20 years a constant increase, the consumption of the most important wheat product, namely wheat flour, has shown a steady decline. While the per capita consumption decreased from 172 pounds in 1930 to 136 pounds in 1950, the total consumption went down only from 508 to 487 million bushels due to the population increase. The difference between increasing production and decreasing consumption was made up by increased export of wheat. However, it is not very likely that further large expansion of wheat production could be disposed of on foreign markets, while there is every indication that domestic consumption will further decline. Consequently marginal wheat areas will probably be retired to forage crops or pastures and we may expect that about the same volume of production of wheat will be maintained during the next 10 years with acreages decreasing in relation to increased yield per acre. The effect of a 30 percent productivity increase in wheat without increased volume of production would be a reduction of man-hour requirement of about 100 million or a technological displacement of 50,000 farm workers.

(*d*) Other food and feed grains will probably show similar labor savings upon application of modern methods of agricultural chemistry as we have seen with corn and wheat and, without going into details about minor crops, we may assume that an expected gain in productivity of labor of about 30 percent attributable to chemical agriculture without corresponding increase in production will cause a decrease of about 160 million man-hours per year equivalent to a technological displacement of 80,000 workers.

(*e*) Haymaking is a very large consumer of farm labor and has shown over the last 10 years a small but constant decline in man-hour requirements. This was due mainly to the introduction of very efficient haymaking machines such as mowers, balers, choppers, stakers, etc. Although mechanization of haymaking is expected to continue and irrigation, fertilization, weed control, and better curing methods will exert an additional effect upon labor efficiency, the expected increasing demand for hay caused by larger consumption of meat and dairy products is most likely to absorb the increased yield per acre as well as of additional acreage retired from corn and small grains. For this reason no great change in man-hour requirements for haymaking is expected.

(*f*) Tobacco is one of the few crops which over the last 10 years showed a considerable increase in labor requirement. This is not only due to the enormous increase of consumption of tobacco products, especially cigarettes, but also to the fact that modern agricultural technology has not yet invaded the field of tobacco production. Almost all the work in the tobacco fields is still done by hand and tobacco growing is mainly done by small farmers in connection with other crops. Considering the many losses due to weeds, insects, fungi, virus disease, chemical agriculture appears to have a prospective field in tobacco production. Presently calcium cyanamide is being used to destroy weeds and soil-born diseases, but this is only a small beginning. Considering the smallness of the tobacco growing enterprises and the extreme conservatism of the tobacco growers not much change can be expected and such labor savings as he might be able to obtain will just take care of increasing production. In the main the picture will not be much changed.

(*g*) Cotton is at the present time the crop that requires the largest share in the amount of farm labor and here chemical agriculture in combination with increased mechanization will probably cause the highest degree of labor saving and displacement of farm workers. Preemergence treatment of cotton fields with dinitrophenols has proved successful in the control of weeds thus reducing the labor needed for cultivation (57). Spraying and dusting with insecticides which is done to ever larger extent by airplane adds greatly to labor saving by reducing crop damage (58). And chemical defoliation of cotton by dusting or spraying with calcium or sodium cyanamide, sodium monochloroacetate, potassium cyanate, or pentachlorophenol not only permits more efficient machine harvesting but also greatly expedites hand picking (59).

Complete mechanization and "chemicalization" of cotton production is now the goal of an over-all program in which 15 Southern States cooperate with the United States Department of Agriculture. What tremendous labor saving could be obtained is shown by studies in the Mississippi Delta which demonstrated that an average of 155 man-hours is required to produce one bale of cotton with one-row mule-drawn equipment, hand-chopping and hand-picking, while complete mechanization would reduce the time to produce one bale of cotton to only 10 man-hours (60):

Time required for production of 1 bale of cotton

	Man-hours
Manual operations:	
Land preparation, seeding planting	28
1-row mule equipment chopping	35
Hand picking without defoliation	92
Total	155
Machines and chemicals:	
Tractor seeding, cultivation flaming, weed and insect control	5
Defoliation and mechanical picking or stripping	5
Total	10

The bountiful cotton harvest of 17,291,000 bales which the year 1951 brought to this country required for all (preharvest and harvest) farm work only 2,230 million man-hours, equivalent to 1,115,000 farm workers (operators and hired hands), while the much smaller cotton harvest of 10,744,000 bales in 1941 required total man-hour expenditures of 2,177 million man-hours, equivalent to 1,089,000 farm workers. Yet, in 1951 only 8 percent of the total cotton production was mechanized, though the regional differences were as large as is indicated by the 34 percent mechanization in California, 3 percent in the Mississippi Delta, and 1 percent in Alabama. Considering the great inducement to mechanization which the present labor shortage and the development of ever more efficient chemicals and equipment brings about, we may expect that mechanization and the use of chemicals will progress at an ever-increasing rate in the near future, while cotton fields that do not readily lend themselves to modern farm practices will be abandoned or used for other crops or pastures. It is, therefore, a quite conservative prediction that within a period of 10 years mechanization will increase from 8 to 50 percent of the total cotton production. What this means for the labor market can be easily calculated from the man-hour requirement of 155 respectively 10-hours per bale in non-mechanized respectively mechanized operations. Assuming the present volume of production remains unchanged—and there is, as will be shown, much validity in this assumption—we have:

	Percent mechanization	Million man-hours	Workers
1951	8	2,230	1,115,000
1961	50	1,328	664,000
Technological displacement			451,000

While cotton production has bounced from last year's low of 10,012,000 bales to this year's bumper harvest of 17,291,000 bales, we must not expect further large increases in cotton production because of the increasing competition of artificial fibers at home and of cotton production abroad. Even if we make allowance for expected population increase and probable increase of per capita consumption of textiles for personal and industrial use, the most we may hope for is that cotton production in this country will remain stable subject to weather conditions. In other words, on ever smaller acreages and with increasing use of fertilizers, chemicals, and mechanical appliances, the same total yield will be obtained with a sharply reduced labor force. It might be added that, in case of total mechanization of the entire cotton production of the United States, the present crop could have been obtained with only 85,000 workers.

(*h*) Truck crops are the next largest consumers of farm labor. They comprise all our vegetables and some fruits, such as melons, but do not include potatoes, sweetpotatoes, dry beans, and dry peas. While in other lines of crop production we noticed considerable decreases in man-hour requirements during the last 10 years, the man-hours required for vegetable growing have increased from 1,121 million man-hours in 1941 to 1,215 million man-hours in 1950, or 8.4 percent. This is due not only to the large increase in vegetable consumption but also to the very slow progress made in mechanization and labor-saving devices. Yet, while the prospects for labor economy in vegetable growing are not so spectacular as in corn, wheat, and cotton, mechanization and especially "chemicalization" offer distinct advantages of which the vegetable growers certainly will avail themselves in the years to come.

While it is not possible to describe in detail every labor-saving operation in the cultivation of the some 30 different crops that fall under the heading "Truck crops," some general observation can well be made that apply to most of them. In the first line, truck crops are the ones which lend themselves best to pelletization, and much labor can be saved by proper spacing and avoidance of thinning or replanting, which are very laborious and time-consuming operations. However, since pelletization has not yet been tried on a large scale, no assumption as to possible labor savings on account of this new practice will be made. Quite different is the situation with chemical weed control, which has reached already a high degree of perfection in many vegetables. Controlling weeds is perhaps the largest single item in the cost of vegetable production. This is because it is virtually impossible to cultivate these crops close to the row and to remove weeds without hand work. However, if weeds are not removed when they are small, they offer serious competition to vegetable crops and may cause great losses in both yield and quality. On the other hand, many herbicides proved very injurious to most vegetables, while others left residues on them which altered taste and flavor or made them directly unsuitable for human consumption. Fortunately, some vegetables showed remarkable resistance to certain weed killers, and intensive search for substances that, while effective weed killers, have no harmful aftereffect was also quite successful. To mention only a few instances, calcium cyanamide is an effective weed killer in asparagus growing; sodium trichloroacetate shows promise in weed control of beets; petroleum distillates are used as preemergence herbicides for carrots, parsnips, celery, and parsley; potassium cyanate has been used as postemergence spray for onions. Naturally also the use of insecticides has greatly increased the yields per acre or per man-hour. Since so much progress has been made or is to be expected in the near future in harvesting mechanization of vegetable crops, we may well assume that the expected large increase of consumption of all kinds of vegetables will be taken care of without increased labor requirements by the simple expedient of chemical agriculture.

(*i*) The relatively small labor requirements for "Vegetables except truck crops" is to a very large extent caused by the requirements for potato growing, which in 1941 needed 190,797,000 man-hours to produce 355,774,000 bushels, while in 1950 only 169,149,000 man-hours were required to produce 439,500,000 bushels. While in 1941 the production of 100 bushels of potatoes required an average of 53.65 man-hours, in 1950 only 38.56 man-hours were needed, a decrease of 28.13 percent in 10 years. While we must not expect a further large increase in potato production, mechanization and especially "chemicalization" of potato production will make great progress. Calcium cyanamide has proved to be an effective weed killer for potato fields, and most significant are the various chemical methods to cope with the insect damages caused by the Colorado potato beetle, the fungus diseases such as early and late blight, and the virus diseases of potatoes. Mechanical harvesting machines which reduced the labor required for hand digging and chemicals to destroy the vines and make harvesting more efficient have gained momentum in areas of mass production and will further expand into other potato-growing areas. Therefore, it appears to be very conservative to assume another 28.13-percent reduction in man-hour requirements for potatoes alone, or 47,600,000 man-hours corresponding to a gainful employment of 23,800 farm workers. Since similar progress will be made in other crops belonging to this group, a total saving of man-hours will be achieved in the next 10 years amounting to 73 million, causing displacement of 36,500 farm workers.

(*j*) Sugar crops, that are mainly cane sugar and beet sugar are due for considerable savings in man-hours as a result of the combined impact of mechanization and "chemicalization." In sugar-beet growing the preemergence treatment with sodium trichloroacetate and the planting of decorticated single seeds make the backbreaking stoop labor for thinning and hoeing unnecessary, while mechanical planting and harvesting reduce the remaining hand-labor requirements. While with manual work 1 acre of sugar beets requires a total labor expenditure of 68.1 hours, full mechanization requires only 15.1 man-hours per acre (61). The average sugar-beet yield is about 12 tons per acre, and 1 ton of beets yields about 300 pounds of sugar. Thus the grower who does not employ modern labor-saving devices needs 2 hours to plant, grow, cultivate, and harvest sugar beets for the manufacture of 100 pounds of sugar, while the grower who uses fully mechanized operations and chemicals for weed and insect control needs only 25 minutes to do the same work. This enormous labor saving will in all probability be generally adopted within the next 10 years. Thus in 1950, when 915,000 acres of sugar beets were harvested at an average mechanization ratio of 60 percent, about 37.4 million man-hours were needed, while under total mechanization and "chemicalization" only 15 million man-hours would have been needed for the same acreage. Thus we may well expect within the next 10 years a labor saving of 22.4 million man-hours, corresponding to a displacement of 11,200 farm workers. Sugarcane cultivation has not yet reached such high degree of mechanization and corresponding labor saving as did sugar-beet growing. However, mechanization, well under way before the Second World War, was very much stimulated by labor shortage during the war years. Mule-drawn row plows and cultivators have been largely replaced by tractor-drawn equipment (62). Preemergence treatment with 2,4-D proved superior to flaming for control of broadleaved plants, while sodium trichloroacetate, applied at a rate of 5 pounds per acre, inhibited the growth of the very noxious and damaging Johnson grass without injuring sugarcane (63). Thus, while at the present time sugarcane still requires about twice as many man-hours per acre and progress will be much slower than was observed in sugar beet, we may yet expect considerable savings in man-hours, once the present trends of mechanization and "chemicalization" come to full fruition. Additional savings will be obtained through the introduction of new pest-resistant cane varieties and more efficient chemical pest control. It thus appears very conservative to expect within the next 10 years a total labor saving in sugarcane production in the continental United States (mainly Louisiana and Florida) of about 50 percent, which means 68 million man-hours, or 34,000 workers, and, together with sugar beets, a total displacement of 45,200 farm workers.

(*k*) Fruits and nuts, oil crops, and all other crops may well expect considerable progress in mechanization and the application of chemical labor-saving devices. Without going into detail, we may just mention improved weed control, eradication of fungus and virus diseases, more efficient insecticides and rodenticides, chemical fruit thinning, and prevention of premature blossoming and dropping of fruits. Although we may expect large increases in production in all these agricultural products, the increase in labor productivity will still be greater. Thus we may very conservatively expect a total labor displacement of 20 percent, or 129,300 workers.

(*l*) Farm maintenance, which includes labor for fencing, farm woods, pastures, etc., will be greatly facilitated by modern devices and equipment, automotive machinery, electricity, greater skill in performance. Thus we may add an additional 20 percent to labor saving which would correspond to the technical displacement of 274,400.

Prospective technological displacement of farm workers in 10 years

	Farm workers
(*a*) Livestock production and animal products	0
(*b*) Corn	400, 000
(*c*) Wheat	50, 000
(*d*) Other food and feed grains	80, 000
(*e*) Haymaking	0
(*f*) Tobacco	0
(*g*) Cotton	451, 000
(*h*) Truck crops	0
(*i*) Vegetables except truck crops	36, 500
(*j*) Sugar crops	45, 200
(*k*) Fruits and nuts, oil crops, other crops	129, 300
(*l*) Farm maintenance	274, 400
Total farm labor displacement	1, 466, 400

As can be gathered from table IV, the prospective technological displacement of farm workers during the next 10 years has been calculated from the regression formula obtained for the secular trend in farm-labor employment at 1,535,000 farm workers. If we now get from considerations based upon the effects of progressing mechanization and "chemicalization" of agriculture a displacement of 1,466,000 farm workers, the agreement between the calculated figure and the estimated one must be considered very good. In view of the many uncertainties involved, the difference of 69,000 farm workers, or 4.5 percent, being far below of what can be reasonably predicted for a time 10 years from today.

Considering the rapid change in agricultural technology which we are now witnessing, it would be presumptuous to try to forecast conditions 20 years from now. But having proved the probability of the reduction of the agricultural labor force by 1,535,000 farm workers for the next 10 years, we may well trust our regression equation expressing an increasing impact of technological changes also for the subsequent decade and assume a further reduction in the agricultural labor force of 1,935,000 farm workers within the realm of the probable future development. Such development will bring down the number of farm workers (plus operators) from its 1950 level of 9,320,000 to 7,785,000 in 1960 and to 5,850,000 in 1970.

That such figures are not wild guesses but quite reasonable and scientifically substantiated, we may infer from further developments in chemical agriculture that in all probability will take place within the next 10 or 20 years and put agricultural production on the same footing with industrial or factory production. One such development might well be hydroponics or soilless agriculture, a method of growing plants in water to which chemicals are added, rather than in soil (64). This growing of crops without soil with the aid of proper plant-nutrient formulas will in some cases increase the yield and improve the quality of crops and in all instances keep away soil-borne diseases. Tomatoes, beans, cucumbers, and many other plants have been grown already with success on a commercial basis, and it is only a question of time when large "food factories" will be economically feasible.

Another important development by which man could make himself partially independent from the vagaries of nature in food production will be the commercial production of proteins, fats, and vitamins by methods of industrial fermentation. Food and fodder yeast are already produced on a large scale for the increase of our protein and vitamin supply (65), and fat will be soon available through the fermentation of the fungus *Oïdium lactis* (66). To what extent these harnessing of microbiological processes for food production will change agricultural employment cannot be predicted at this moment, though it is fair to say that the industrial manufacture of fat and protein from carbohydrates will tend to decrease the labor required for farm work.

And yet we are but at the threshold of another discovery of tremendous importance which may well be able to change not only agricultural practices but the entire way of life. This discovery is the solution of the enigma of photosynthesis by which the green plants built their vegetable matter, the basis of all vegetable and plant life on this planet, from water and carbon dioxide. This synthesis is done with the help of the plant pigment chlorophyll, which has been already isolated and the chemical composition of which has been determined. We also know by now to a certain degree how chlorophyll acts, but have not yet been able to reproduce its action outside the plant cell. Here again it is only a matter of time till we will be capable to imitate the most basic physiological process, producing organic substances in factories just as plants do it in their cells.

IV. Conclusions

In the preceding chapters we described the trend in agricultural employment as it is affected by rapid changes in agricultural technology. We endeavored to arrive at a prediction as to the probable development of demand for farm labor in the near future. There can be no question that these developments are bound to gain momentum as time goes on. Eventually they will exercise tremendous influence upon agricultural practices and rural life in the United States and other countries. This is the reason why sociologists and economists, statesmen, legislators, and politicians should pay considerable attention to these scientific and technological developments while they are still in their initial stages instead of waiting until such revolutionary changes have become so widely adopted that adjustment to the new situation will be fraught with great dangers and difficulties.

In times of economic stagnation and depression the main task of the legislator consists in the stimulation of progress as far as this can be achieved in a free society by legislative means. A time of rapid change and expansion, however, requires such legislative action as will best preserve our cherished political heritage and prevent our most valuable social and cultural assets from being drawn into the whirlpool of chaotic disruption. Indeed, the greatest legislative skill and utmost prudence are needed in order to lead the revolutionary forces of modern science and technology into evolutionary channels where their creative energies will promote the progress and welfare of the Nation.

Such legislative action appears particularly essential when it comes to the preservation of the traditional pattern of rural life in the United States. This pattern has been and still is the wellspring of American nonconformism, individualism, and democracy. In contrast to the rural life of most other countries which originated in a feudal system and where there are still millions of peasants dominated either by a wealthy and powerful class of landlords or, under communism, by a ruthless bureaucracy, the American farmer has been a freeman ever since he has settled in this country. His participation in the political and cultural life of this Nation is one of the cornerstones of our democracy.

We have an instinctive repugnance against subjecting our free society to the rule of feudal landlords or totalitarian bureaucrats. We also feel this same repugnance against sacrificing our democratic institutions on the altar of science for the sake of greater efficiency, better economy, or larger productivity. We would not allow anyone to use his scientific knowledge or technological skill to gain for himself privileges which require the abridgment of the rights of other citizens. But chemicals are very powerful weapons and he who wields them, whether manufacturer, distributor, or operator, could use them for monopolistic practices if not restrained by proper legislation. Furthermore, the strong competitive advantage that large contiguous areas planted with the same crop offer to big farmers, especially in chemical agriculture, will constitute a strong force toward undesirable agricultural concentration if no action is taken to protect small farmers against absorption or elimination by large-scale operators.

However important these aspects of chemical agriculture are for our economic and social life, many of them go beyond the domain of the United States Senate Committee on Labor and Public Welfare. Therefore, we have restricted our study to those effects which foreseeable changes in agricultural practices, especially the introduction of chemicals as labor-saving devices, will have on labor demand and employment possibilities in agriculture and indirectly on the entire labor market of this country. Ways and means will have to be developed to make the transition from old to new employment conditions take place with a minimum of social and economic disruption and dislocation of the rural population.

There is probably no single factor in a man's life that plays such a dominant role as does his profession or occupation. Nothing determines his cultural, social, and economic life more than the work he does every working day. Next to his occupation the physical and social environment in which he was brought up and to which he has become adjusted exert greatest influence upon the development of his personality. If a change should become necessary in occupation, environment, or both, everything should be done to prevent such change hitting an individual suddenly, with disastrous psychological and economic consequences. A planned transition should be facilitated. Instead of having both occupation and environment altered simultaneously it would be preferable to retain either one or the other to give the person some measure of security and contentment.

In many instances displaced farm workers may find agricultural occupation in newly developed farming areas of this country. If public development work now under way is continued and all authorized development plans are completed, about 4.5 million acres of cultivable land could be brought under irrigation in the next decade. At the same time about 8 million acres could be improved by drainage or clearing. About half of this land development would be on existing farms and the other half would consist in development of new land. In addition to the 12.5 million acres that could be developed during the next 10 years, still more land is capable of economic utilization through irrigation, clearance, and drainage (67). Modern chemical practices, such as the eradication of sagebrush with efficient herbicides, destruction of mosquitoes in swamp areas with DDT, reforestation and reseeding from the air, will make land development work more efficient and economical. Although we must warn against undue optimism about absorbing displaced farm workers through internal agricultural colonization, a figure of at least 250,000 farm workers appears to be a rather conservative estimate of the number that could be accommodated through new settlement opportunities or improvement of existing agricultural areas.

Even more desirable than retaining displaced farm workers in their customary occupational activity, though in an entirely new and unaccustomed environment, appears another solution, that of providing them with new opportunities to earn their livelihood at the place where they live. Nothing would be more disruptive to our political institutions and the American way of life than to have displaced farm workers or small farmers migrating into overcrowded urban areas and a deserted countryside producing with a minimum of labor all the food needed for our growing population. Even if all displaced farm people could find gainful employment in a few large cities while agriculture was raising bountiful harvests with very little manual work, such a situation is certainly not satisfactory from a social point of view, even though it might be from a strictly economic viewpoint.

For these reasons it appears essential to the welfare of our Nation and to the stability of its economic and political life to retain displaced farm workers on the land and to create job opportunities and employment possibilities at or near the place where technological displacement is anticipated. A most important consideration should be the maintenance and security of the family life of displaced farm workers. Technological trends and scientific developments of recent years should draw attention especially to the following employment opportunities:

(*a*) The progressive mechanization and "chemicalization" of agriculture will require many persons with special skills on both the professional and subprofessional levels. For aerial farming we need, in addition to one pilot for each plane, one licensed mechanic with two helpers, for each five planes. In general, we may assume that each plane put into operation creates job opportunities for three displaced farm workers. Therefore, if we assume that we will have about 20,000 planes engaged in agricultural work 10 years from now, new employment opportunities would arise for about 60,000 persons. In addition to airplanes there will be many complicated farm implements and machines that will need constant servicing. Finally the storage, transportation, mixing, and application of agricultural chemicals will offer new job opportunities to men with some elementary familiarity with chemistry and special skill in handling dangerous or poisonous substances.

(*b*) There is an estimated 200 million tons of crop residues and agricultural waste remaining on farms every year. Although large amounts of this refuse should be left there in order to help building up depleted soils, as yet none of it, or only very small quantities, is utilized for other purposes. In a time of great shortage of essential raw materials for chemical and other industries many crop residues could be utilized economically: corncobs for the manufacture of furfural, an important solvent and starting product for all kinds of chemical products; straw for the manufacture of paper and cellulose; whey for making lactic acid; beet pulp for the manufacture of pectin which among other uses is needed for making fruit jellies. This list could be greatly expanded, though we only wish to indicate that out of the need for greater farm economy and better utilization of our natural resources arose a new branch of chemical science, namely chemurgy, which is devoted to the study of the chemical conversion of farm by- and waste-products to obtain needed raw materials for industry. It is conceivable that small chemical reducing and processing equipment could be designed and chemurgic plants of moderate size could be scattered through the rural areas so that the disadvantages of small-scale production would be compensated for by ready availability of raw material and labor. Thus chemurgy offers an opportunity to preserve not only our natural resources but—what is more valuable—our human resources as well.

(*c*) Finally, there is need for an orderly and planned development of industry in the areas affected by these technological changes in agriculture. Such an industrial development should be conceived in terms of providing good jobs at decent wages for displaced agricultural workers at the same time that care is taken that these areas do not provide a haven for enterprises which are seeking a supply of manpower which can be easily subjected to substandard wages and working conditions. Higher living standards, especially of those farmers and farm workers who can stay on the farm and avail themselves of the advantages of modern technology, and improved taste in furnishing rural homes could lead to a replacement of cheap, mass-produced merchandise by more elaborate manufactured and even hand-made goods. Better appreciation of the products of rural industries carrying the stamp of regional characteristics could eventually lead to a revival of some home industries and rural handicraft. In this way many skills and talents that are now dormant could be developed and give gainful employment to displaced farm workers at or near the place where they and their families live.

While the expected rapid progress of chemical agriculture will greatly increase the demand for agricultural chemicals as well as for implements of application, we must not expect any great relief for rural under- and un-employment from expansion in the manufacture of agricultural chemicals and appliances, however great. The chemical industry in particular with its compact production force and efficient organization has always carried out its operations with a minimum of manual handling. As chemical production increases, less and less labor will be required for each additional unit of product. In this respect it is quite significant that the manufacture of 1 pound of 2,4–D or 2,4,5–T, either substance being a most powerful weed killer, requires only 0.00896 man-hours which at the cost of $1.50 per hour is less than 1.5 cents (68). One chemical worker turns out 100 pounds of 2,4–D or 2,4,5–T every working hour and could easily double this output, if larger machine capacity would be installed. The figures for man-hour production in other lines or agricultural chemicals are not very different.

While it would take a man with the hoe about 20 hours to weed out 1 acre of a heavily infested cornfield (a practice no more in use in the United States, but still adhered to in less developed countries), and about 1 hour to accomplish the same job with a two-row horse-drawn cultivator (the most prevalent practice in the United States), the application of only half a pound 2,4–D as a postemergence spray requires only 0.2 hours per acre. Thus we obtain the ratios:

manual weeding : mechanical weeding : chemical weeding = 100 : 5 : 1.

In cottonfields the total hand weeding operation requires 54 hours per acre and is still widely practiced in the United States, whereas weed eradication with dinitro compounds and oil treatment requires only 5 hours per acre. Conditions are similar with many other crops as far as labor saving is concerned. It appears that since one-half pounds of 2,4-D saves 4 man-hours, a chemical worker producing 100 pounds of this substance in an hour causes a technological displacement of 800 man-hours. Thus one may say that the contribution of 1 chemical worker to the food and fiber production is about equal to that of 800 farm workers as far as weed eradication is concerned. Furthermore, since this great efficiency of the chemical worker could be further increased if demand for agricultural chemicals should require their manufacture on a larger scale, there appears practically no man-hour demand on the credit side of the employment ledger for many man-hours of displacement at the debit side.

Whereas the production of agricultural chemicals offers no additional employment opportunity to displaced farm workers, the distribution and mixing (including transportation, storage, and handling) will create some new jobs. These, however, could in no way make up for the losses to be expected in farm employment with the general adoption of chemicals as labor-saving devices. Since many of the substances used in chemical agriculture are subsumed somewhat loosely under the term "economic poison," it has become necessary to regulate their marketing by special legislation, namely, the Federal Insecticide, Fungicide, and Rodenticide Act (69), which takes their specific fire and health hazards into consideration. Possible harmful effects of residues of agricultural sprays and dusts on food products have been studied by the Select House Committee on Use of Chemicals, Pesticides, and Insecticides in and With Respect to Food Products (70) and also by the Committee on Food Protection of the National Research Council. The latter committee in a recent report stated that the most widely used insecticide, DDT, is not harmful to humans and the beneficial effects of a wide application of insect-, disease-, rodent-, and weed-destroying chemicals to farm workers and rural health must not be overlooked.

Considering the health and living conditions of farm workers, it is natural that they will be greatly affected by changing physical environment and occupational conditions. The elimination of malaria and hookworm in the Southern States has already contributed a great deal to working efficiency and life expectancy in this region. Improvement in education, sanitation, nutrition, medical care, and economic conditions, and—last but not least—the general application of pest-destroying chemicals will result in further progress. An illustration is the common housefly, which has been found to be the carrier of many diseases and can be exterminated with DDT.

Great as the satisfaction is which we may draw from these betterments, we must not overlook some adverse effects of these generally desirable developments. Greater working efficiency of the farm laborer and elimination of time losses due to diseases and their after effects means greater labor supply per capita and consequently higher displacement figures. On the other hand, decreasing fertility and increasing life expectancy in rural areas are bound to put a larger percentage of the rural population into the labor market, especially when the longer life duration is accompanied by good health and working ability. Since the progressive mechanization and "chemicalization" of agriculture will continue to eliminate those chores which formerly required heavy toil and manual exertion, older people will be useful much longer on the farm than they used to be and thus replace younger workers. But the number of older people will constantly increase and, though a much greater percentage of them will be able to work or retire on their own means, the number of indigent persons of old age, especially former farm workers, will also pose serious social and economic problems for which solutions will have to be found.

We are now living in a time of great international tension when this country is threatened by dangers more serious than it has ever had to face in its history. It is, therefore, necessary that we be prepared to meet these dangers, if they ever should arise. Consequently, a great part of our material and manpower resources must be dedicated to defense purposes. This in turn causes shortages of labor, farm machinery, and agricultural chemicals and retards the normal development of chemical agriculture. But we must not be less prepared for peace than for war. For this reason we must study the long-run economic trends in industry and agriculture as they are affected by rapid changes in technology and important scientific developments. Above all, we have to develop constructive economic policies in order to make science and technology serve human welfare and liberty.

V. References and Bibliography

(1) Salter, Robert M., Chemicals as Farming Tools, Science, August 24, 1951, p. 3.
(2) National Resources Committee, Technological Trends and National Policy, House Document No. 360, 75th Cong., 1st sess., Washington, June 1937, p. 289.
(3) Smith, J. Russel, and M. Ogden Phillips, Industrial and Commercial Geography, New York, 1950, p. 300.
(4) Board of Governors of the Federal Reserve System at Washington, Federal Reserve Index of Industrial Production, October 1943, pp. 24, 41, 42, 95. Industrial Production by Industries, Annual Indexes, May 1951, pp. 1 and 3.
(5) Aries, Robert S., and Rudolf M. Cziner, Growth of the American Chemical Industry, Industrial and Engineering Chemistry, August 1951, pp. 1712-1722.
(6) Fabricant, Solomon, The Output of Manufacturing Industries, 1899–1937, National Bureau of Economic Research, New York, 1940, table 40, p. 221.
(7) United States Bureau of the Census, Historical Statistics of the United States, 1789–1945, Washington 1949, p. 63, table D1–10.
(8) Barger, Harold, and Hans H. Landberg, American Agriculture, 1899–1939, A Study of Output, Employment, and Productivity, National Bureau of Economic Research, New York, 1942, p. 253.
(9) Hecht, Reuben W., and Glen T. Barton, Gains in Productivity of Farm Labor, United States Department of Agriculture Technical Bull. No. 1020, Washington, December 1950, pp. 4–5.
(10) Encyclopedia of Social Sciences, vol. I, p. 553, New York, 1937.
(11) Hecht, Reuben W., l, c., p. 54.
(12) The Economic Report of the President, transmitted to the Congress, Washington, January 1951, table A–11, p. 181.
(13) United States Department of Agriculture, Agricultural Statistics, 1950, Washington, 1950, table 693, p. 649.
(14) Developed by Dr. John H. Smith, American University, Washington, D. C., who graciously assisted in numerical calculations involved. Viz also Max Sasuli, Trend Analysis of Time Series, the Brookings Institution, Washington, 1934, pp. 59–62.
(15) Wool, Harold, Long-Term Projections of Labor Force, United States Department of Labor, Bureau of Labor Statistics (paper presented before the Conference on Income and Wealth of the National Bureau of Economic Research, New York, May 25, 1951.)
(16) Hecht, Reuben W., l. c., table 57, pp. 102–103.

(17) Hurst, W. M., and L. M. Church, Power and Machinery in Agriculture, United States Department of Agriculture Miscellaneous Publications No. 157, April 1933, and private information from the Office of Farm Machinery, Bureau of Plant Industry, Soils, and Agricultural Engineering, United States Department of Agriculture, Beltsville, Md. Viz also Erich Zimmerman, World Resources and Industries, New York, 1951, p. 160.
(18) United States Department of Agriculture, Agricultural Statistics 1950, Washington, 1950, table 692 on p. 648, supplemented by direct information from the Bureau of Agricultural Economics of the United States Department of Agriculture, Washington, D. C.
(19) United State Department of Agriculture, Science in Agriculture, The Yearbook of Agriculture 1943–47, Washington, 1947, pp. 577–582.
(20) Collings, Gilbert H., Commercial Fertilizers, second edition, Philadelphia, 1941, pp. 357 and 362.
(21) Went, Frits Warmolt, Phytohormones, New York, 1937, pp. 70–71, 110, and 137–139.
(22) C. L. Hammer and H. B. Turkey, The Herbicidal Action of 2,4,5–T, Science, vol. 100, pp. 154–155, Washington, 1944.
(23) Bonner, James, Plant Biochemistry, New York, 1950, p. 441.
(24) Batjer, L. P., and M. H. Hoffman, Fruit Thinning With Chemical Sprays, United States Department of Agriculture Circular No. 867, Washington, March 1951, pp. 2 and 29.
(25) United States Department of Agriculture, Science in Farming, l. c., p. 264.
(26) National Cotton Council, Chemical Defoliation of Cotton, Memphis, Tenn., 1951, pp. 1 and 5–6.
(27) Report of the Administrator of Agricultural Research, United States Department of Agriculture, Washington, 1950, pp. 130–131.
(28) Private Information from the Bureau of Animal Industry, Agricultural Research Administration, Beltsville, Md.
(29) Shepard, Harold H., The Chemistry and Action of Insecticides, New York, 1951, p. 1.
(30) Frear, Donald E. H., Chemistry of Insecticides, Fungicides, and Herbicides, second edition, New York, 1948, p. 83.
(31) Chandler, Asa C., Introduction to Parasitology, eighth edition, New York, 1949, p. 427.
(32) Frear, Donald E. H., l. c., pp. 259–272.
(33) Chandler, Asa C., l. c., p. 183.
(34) Salter, Robert M., l. c., p. 3.
(35) Shepard, Harold H., l. c., p. 1.
(36) Ahlgren, Gilbert H., Glenn C. Klingman, and Dale E. Wolf, Principles of Weed Control, New York, 1951, p. 9.
(37) Shepard, Harold H., l. c., p. 327.
(38) Frear, Donald, E. H., l. c., pp. 259–276.
(39) Ahlgren, Gilbert H., l. c., pp. 52–63.
(40) Salter, Robert M., Recent Research on the Use of Agricultural Chemicals, address at the meeting of the National Agricultural Chemicals Association at Miami Beach, Fla., April 4, 1951.
(41) Hitchner, Lee, executive secretary, National Agricultural Chemical Association, Washington, D. C., private information.
(42) Monahan, A. C., Farming From the Sky, Science News Letter for September 15, 1951, pp. 170–171.
(43) Mitchell, H. B., head, Division of Industrial and Agricultural Aviation, Civil Aeronautics Administration, United States Department of Commerce, Washington, D. C., private information.
(44) United States Department of Commerce, Civil Aeronautics Administration, Industrial Flying, Government Printing Office, Washington, 1948.
(45) Mitchell, H. B., flight operation specialist in charge, Industrial Section, Civil Aeronautics Administration, United States Department of Commerce, Washington, D. C., private information.
(46) Burgesser, F. W., The Use of Coated Seeds in Modern Agriculture, Proceedings of the American Society of Sugar Beet Technologists, New York, 1950, p. 84.
(47) Tisdale, E. W., and Kenneth B. Platt, Pellet Reseeding Trials on Southern Idaho Range Lands, Special Report of the University of Idaho and the Bureau of Land Management, United States Department of the Interior, Washington, D. C., January 1, 1951.

(48) Carl P. Heisig, head, Division of Farm Management and Costs, United States Department of Agriculture, Farm Production Practices, Costs, and Returns, United States Department of Agriculture Statistical Bull. No. 83, Washington, D. C., October 1949, table 25, p. 70.
(49) United States Department of Agriculture, Agricultural Statistics 1950, Washington, 1951, table 693 on p. 649.
(50) Barton, Glen T., agricultural economist, Bureau of Agricultural Economics, United States Department of Agriculture, Washington, D. C., private information.
(51) United States Department of Agriculture, Agricultural Statistics 1950, Washington, 1051, table 430 on p. 354 and table 520 on p. 422.
(52) Frank, Archie H., Artificial Insemination in Lifestock Breeding, United States Department of Agriculture Circular No. 567, June 1950.
(53) Black, John D., Marion Clawson, Charles R. Sayre, and Walter W. Wilcox, Farm Management, New York, 1947, pp. 927 and 941.
(54) Hecht, Reuben W., l. c., pp. 22–23.
(55) Hecht, Reuben W., l. c., table 26 on p. 70.
(56) Ahlgren, Gilbert H., l. c., p. 107.
(57) Ahlgren, Gilbert H., l. c., p. 120.
(58) National Cotton Council of America, Cotton Insect Control, Memphis, Tenn., 1951.
(59) National Cotton Council of America, Chemical Defoliation of Cotton, Memphis, 1951.
(60) Cardon, P. V., Cotton Under the Research and Marketing Act, paper given at the Eleventh Annual Cotton Research Congress, Dallas, Tex., July 27, 1950, p. 5.
(61) Smith, Dudley, Sugar Beet Mechanization and Implications for Puerto Rico, Washington, D. C., March 1948, p. 26.
(62) Arceneaux, George, Sugarcane Culture, in Science in Farming, Yearbook of Agriculture 1943–47, United States Department of Agriculture, Washington, 1947, pp. 855–857.
(63) Ahlgren, Gilbert H., l. c., p. 119.
(64) Ellis, Carleton, and Miller W. Swaney, Soilless Growth of Plants, New York, 1938, pp. 44–60.
(65) Prescott, Samuel Cate, and Cecil Dunn, Industrial Microbiology, second edition, New York, 1949, pp. 249–266.
(66) Prescott, Samuel Cate, l. c., pp. 272–282.
(67) Hope, Hon. Clifford R., chairman, Committee on Agriculture, House of Representatives, Long Range Agricultural Policy, House Document, 80th Cong., 2d sess., Washington, March 10, 1948, p. 9.
(68) Industrial Cost Sheet Data, courtesy Dr. Philip Groggins, head, Section of Agricultural Chemicals, Chemical Division, National Production Authority, Washington, D. C.
(69) Public Law 104, 80th Cong., Federal Insecticide, Fungicide, and Rodenticide Act (H. R. 1237), approved June 25, 1947.
(70) Hearings, House Resolution 323, 81st Cong., 2d sess., Select House Committee on Use of Chemicals, Pesticides, and Insecticides in and With Respect to Food Products. House Resolution 74, pt. I, 82d Cong., 1st sess., Select Committee on Chemicals, etc. House Report No. 3254, 81st Cong., 2d sess., Select Committee on Chemicals, etc.

VI. Acknowledgments

In collection and preparing material for this report, the author received valuable assistance and information from the following persons, whose cooperation is hereby acknowledged with many thanks, though all responsibility remains that of the author:

United States Department of Agriculture

Office of the Secretary: Dr. Louis H. Bean, Mr. Clarence J. Enzler, Miss Catherine V. Shea. Bureau of Agricultural Economics: Dr. Carl C. Taylor, Chief, Division of Farm Population and Rural Life; Dr. Louis J. Ducoff; Dr. Margaret Jarman Hagood; Dr. Reuben W. Hecht; Mr. Glen T. Barton. Agricultural Research Administration:

Mr. E. C. LeClerg, research coordinator; Mr. Maurice R. Cooper, research coordinator. Bureau of Entomology and Plant Quarantine: William A. Baker, Chief, Division of Cereal and Forage Crop Insects Investigation. Bureau of Plant Industry, Soils, and Agricultural Engineering: Dr. Robert M. Salter, Chief of Bureau; Dr. F. P. Cullinan, Assistant Chief of Bureau; Mr. R. B. Gray, head, Division of Farm Machinery; Dr. R. L. Lovvorn, head, Division of Weed Investigations; Dr. Ellsworth Shaw, assistant head. Library: Miss Louise O. Bercaw, assistant librarian. Production and Marketing Administration: Office of Materials and Facilities, Mr. W. R. Allstetter, Deputy Director, Dr. Harold A. Shepard, staff specialist; Sugar Branch, Mr. Ward S. Stevenson, Mr. Linwood K. Bailey.

United States Department of Commerce

Mr. H. B. Mitchell, flight operation specialist in charge, Industrial Section, Civil Aeronautics Administration. National Bureau of Standards, Division of Applied Mathematics and Statistical Engineering: Dr. Churchil Eisenhart, Mr. Joseph Cameron.

United States Department of the Interior

Mr. G. W. Lineweaver, Assistant Commissioner, Bureau of Reclamation; Dr. Marion Clawson, Director, Bureau of Land Management; Mr. Gerald M. Kerr, Chief, Division of Range Management.

United States Department of Labor

Bureau of Labor Statistics: Branch of Manpower Studies, Dr. Harold Wool; Office of Statistical Standards, Mr. Samuel Weiss, Miss Sophie Cooper; Bureau of Employment Security, Dr. John B. Ewing; library, Mrs. Margaret F. Brickett, librarian.

National Production Authority

Chemical Division: Dr. Philip H. Groggins, head, Section of Agricultural Chemicals; Mrs. Laura G. Arrington, industrial specialist.

American University

Division of statistics: Prof. Dr. John H. Smith.

The Johns Hopkins University, Baltimore, Md.

School of Hygiene and Public Health: Dr. G. F. Otto, professor of parasitology.

National Agricultural Chemicals Association, Washington, D. C.

Mr. Lee Hitchner, executive secretary.

O